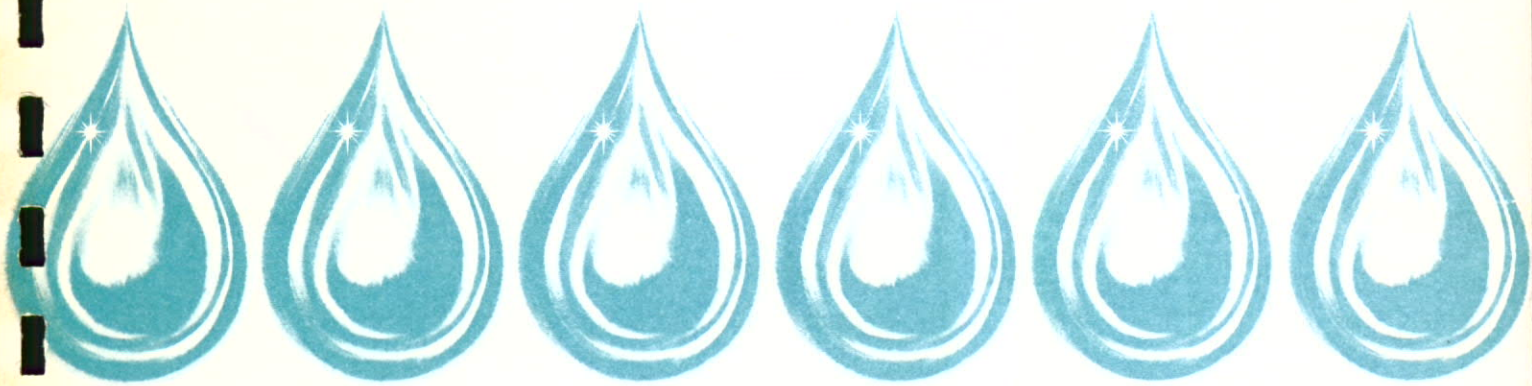


DATA ON SELECTED LAKES IN WASHINGTON

PART 1

UNITED STATES DEPARTMENT of the INTERIOR • Geological Survey 1973
Prepared in Cooperation with
State of Washington
Department of Ecology

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DATA ON SELECTED LAKES IN WASHINGTON, PART I

By

M. R. Collings

Prepared in cooperation with the
State of Washington Department of Ecology

OPEN-FILE REPORT

Tacoma, Washington
1973

CONTENTS

ILLUSTRATIONS

TABLE

DATA ON SELECTED LAKES IN WASHINGTON, PART I

By M. R. Collings

ABSTRACT

This report, the first in a series, describes 22 lakes in western Washington relative to physiographic, physical, chemical, and floral characteristics, and seasonal variations in some of these characteristics. Most of the lakes studied are used primarily for recreation, have origins related to continental and alpine glaciation, and are in areas underlain by glaciofluvial and (or) volcanic deposits that are covered by soils grading from gravel to clay. The cover of the lake basins ranges from conifer forests with some deciduous trees to grasslands and urban developments. The lakes studied range in surface area from 0.27 to 49.4 million square feet, in volume from 3.34 to 2,624 million cubic feet, in mean depth from 11.1 to 70.8 feet, and in maximum depth from 20 to 117 feet.

Generally, the water-temperature profiles of the lakes show total mixing during the winter, with a uniform temperature-depth profile, and, beginning in the spring, thermal stratification which reaches a maximum during the summer, after which the mixing cycle begins again in the late fall. Profiles of the dissolved-oxygen concentration in most of the lakes have the same relative shape as the temperature profiles. However, during the summer eight of the lakes also developed a pronounced positive heterograde zone of oxygen supersaturation in the central part of the depth profile. In several lakes, mineral and nutrient constituents increased from the epilimnion to the hypolimnion during summer stratification. Lake-level fluctuations reflect the precipitation pattern in western Washington.

INTRODUCTION

The lakes of Washington, although a small part of the State's water resource, are subjects of increasing interest and exploitation. As the State's economy and population grow, and as new industries are developed, local hydrologic and water-quality problems involve an increasing number of lakes and reservoirs, and a greater number of "problem lakes" is inevitable. Thus, there is an increasing need for more deliberate and continuing studies of the ponded part of the State's water resource.

Not only do lakes have economically beneficial uses stemming from their reservoir function (for hydroelectric power, flood control, and fisheries, and for irrigation and municipal supplies) but they also have great esthetic and recreational values. These many possible uses of lakes tend to be overlapping rather than mutually exclusive, and thereby require consideration of multiple-use concepts for their most efficient use and proper management.

Purpose and Scope

The trophic conditions of lakes are not easy to document and result from a complex interrelation of physical, chemical, and biological parameters that contribute to lake aging, both natural and induced, as outlined generally in figure 1.

Although lakes are widely recognized for their importance as a many-faceted resource, the data now available on most of Washington's lakes are not adequate to provide the understanding needed for wise water-management decisions. Therefore, this study was designed to help define the aquatic ecosystems of the lakes of Washington. In general, the study consists of a sampling program to obtain physical, chemical, and biological information needed to (1) document the present status of lakes for which little or no information is now available, and (2) establish a basis for reference allowing periodic appraisals of future lake condition.

This is the first of a planned series of reports. It presents data collected on the first 22 lakes studied, all in western Washington (fig. 2). Subsequent reports in the series will describe lakes in other parts of the State as well.

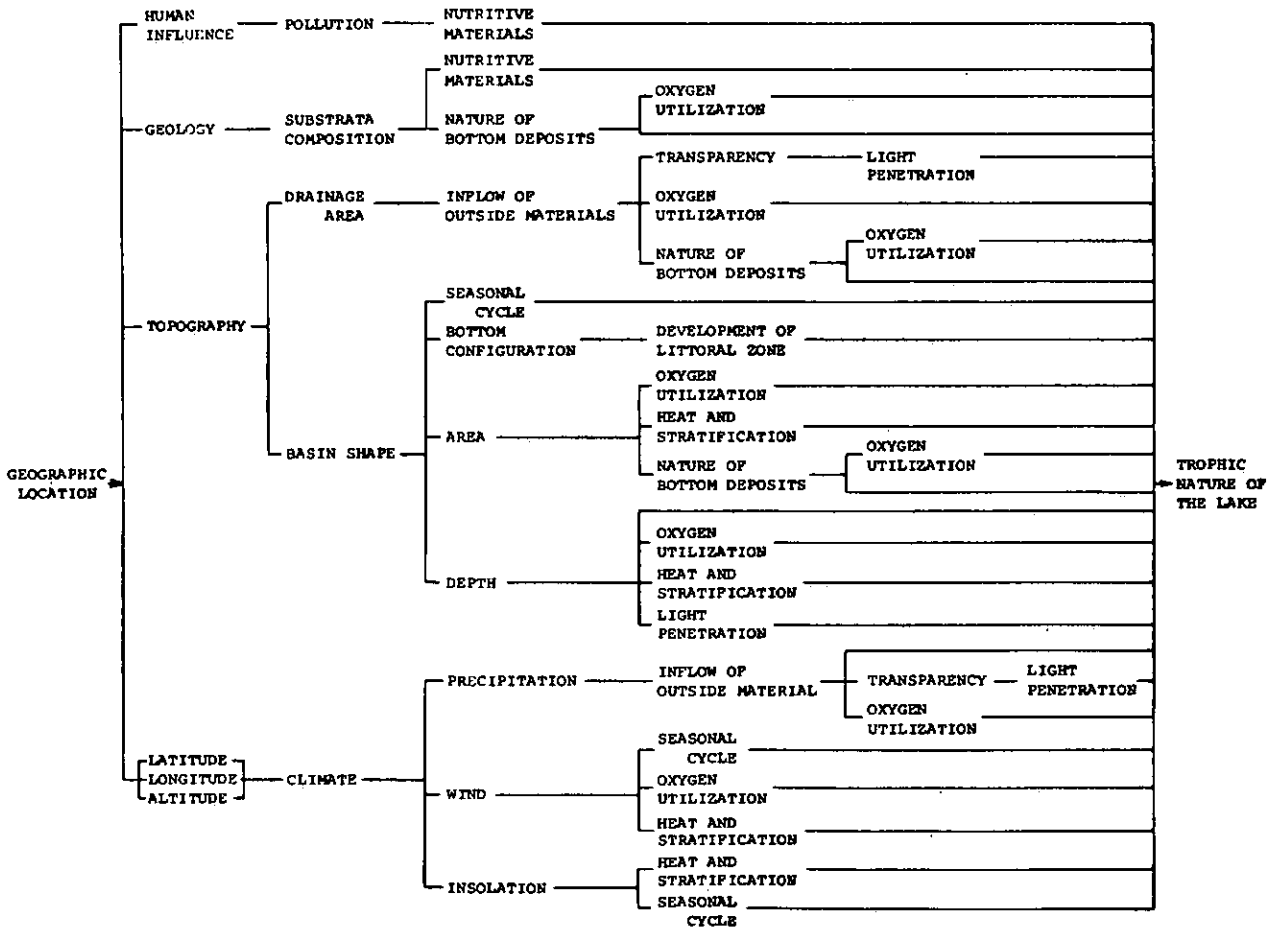


FIGURE 1. – Relations of selected parameters which determine the condition and "age" of a lake (modified from Rawson, 1939).

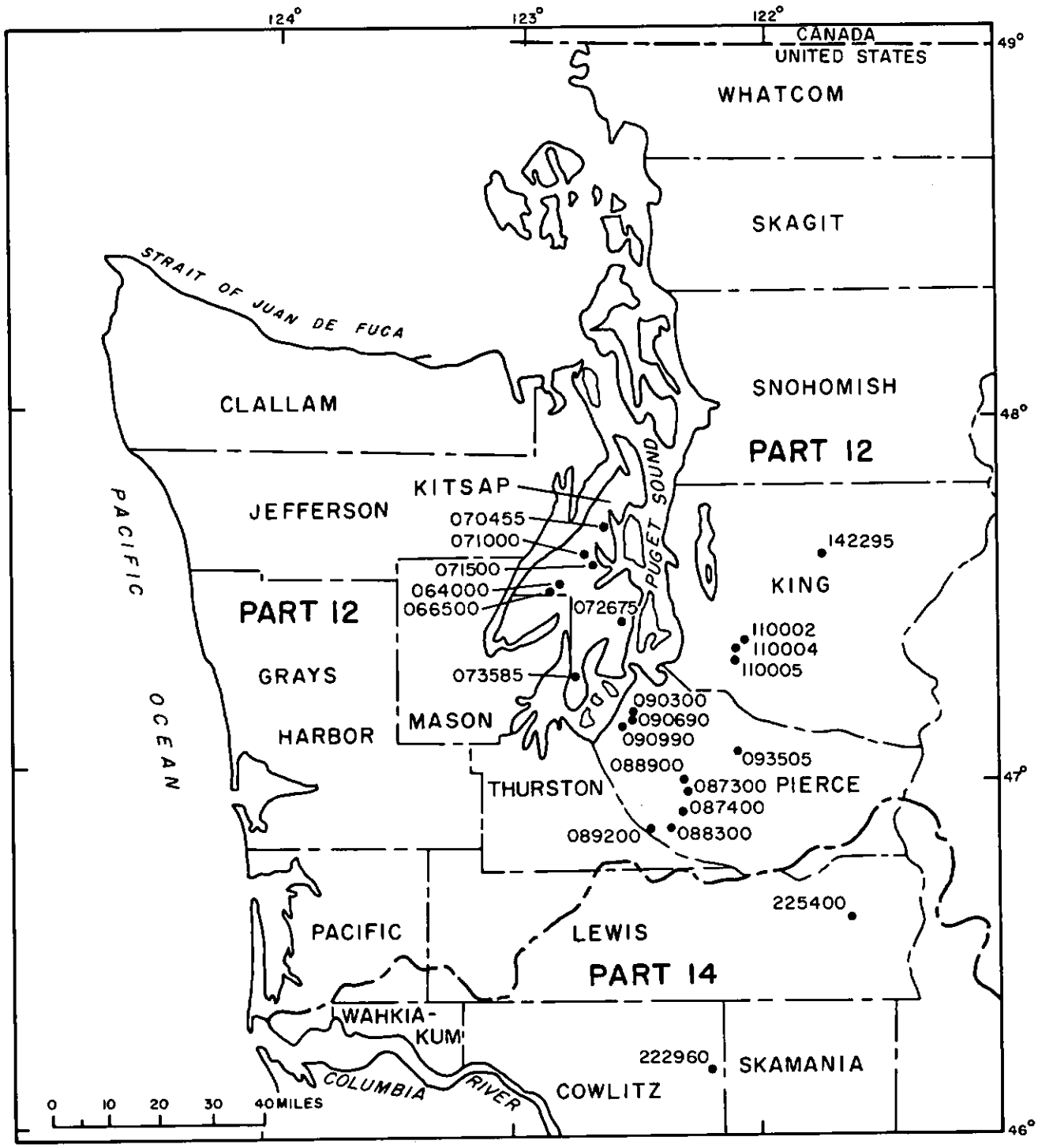


FIGURE 2. – Location of lakes for which data are presented in this report. Lake numbers are described in text and listed preceding lake names in table of contents; for convenience, part prefixes "12" and "14" are deleted from lake numbers on map.

Acknowledgments

This study was made by personnel of the U.S. Geological Survey as part of a program of water-resources investigations in cooperation with the State of Washington Department of Ecology. The author gratefully acknowledges the assistance of the State of Washington Department of Game and R. W. Beck and Associates in obtaining many of the lake bathymetric maps, and for their permission to reproduce the maps. Mr. Bob Sandusky of Washington Public Power Supply System assisted generously by providing transportation to Packwood Lake. The constructive criticism and suggestions of colleagues W. A. Dawson and J. F. Ficke of the Geological Survey materially benefited the final report.

Data Collected and Definitions

In this report, the current status of the lakes studied is documented by data that describe each lake relative to its geographic and geologic setting and physical features, and to the extent of man's development of the lake, the chemistry of the lake waters, and the macrophytes (aquatic plants) in the lake. These data document the lake's condition and provide the basis for evaluation of future changes in the lake. The types and definitions of data collected for the lakes and adjacent areas, and the sources of these data, are discussed below.

The physical setting of each lake is described by location, origin, basin geology, soils, land use and cover, and population. The location of the lake is defined from U.S. Geological Survey topographic maps, by the latitude and longitude of the surface-water outlet (or, if the lake has no outlet, of the southernmost tip of the lake), and by section, township, range and county.

Information on lake origin and basin geology was obtained generally from existing geologic maps and reports, and from field reconnaissance, as follows:

For lakes in Kitsap County--Mission, Panther, Island, Wildcat, and Kitsap Lakes--from Sceva (1957) and Molenaar (1965). For Crescent and Jackson Lakes in peninsular Pierce County, from Molenaar (1965). For lakes in mainland Pierce County--Clear, Ohop, Silver, Tanwax, Harts, American, Gravelly, Steilacoom, and Forest Lakes--from Walters and Kimmel (1968).

In King County, information for Wilderness, Pipe, and Lucerne Lakes came from Luzier (1969), and for Hancock Lake from Huntting and others (1961). For Packwood Lake in Lewis County and Merrill Lake in Cowlitz County, information came from Huntting and others (1961).

Information on the soils of the lake basins came from maps and reports as follows:

For lakes in Kitsap County--Mission, Panther, Island, Wildcat, and Kitsap Lakes--from Wildermuth and others (1939). For lakes in Pierce County--Crescent, Jackson, Clear, Ohop, Silver, Tanwax, Harts, American, Gravelly, Steilacoom, and Forest Lakes--from Anderson and others (1955). For lowland lakes in King County--Wilderness, Pipe, and Lucerne Lakes--from Poulson and others (1952). For mountain lakes--Hancock Lake in King County, Packwood Lake in Lewis County and Merrill Lake in Cowlitz County--from a State soils map (U.S. Soil Conservation Service, undated).

Information on land use and cover were obtained by field reconnaissance during this study. Population data (number of dwellings) for the present (October 1970) were from field observations and were compared to previous numbers as noted on U.S. Geological Survey topographic maps.

Selected physical, chemical, and biological features of each lake are described by a bathymetric map and by depth profiles of selected morphometric parameters, DO (dissolved oxygen) concentration, specific conductance, and water temperature, and by water transparency, seasonal variations of lake stage, surface-water inflow and outflow, mineral constituents in the lake water, major nutrients found in the lake, and area of coverage of lake by macrophytes and genera of dominant macrophytes. The study of macrophyte coverage was made during the fall visit to the lake.

Of the 22 bathymetric maps shown in the report, 19 were obtained from Wolcott (1965), from the files of the State of Washington Department of Game, and from consulting firms. The remaining three lakes were mapped by project personnel, using plane-table methods for location and a recording fathometer for development of cross-section profiles. The majority of the bathymetric maps presented by Wolcott (1965) were made originally by personnel of the Washington Department of Game, using plane-table methods and many point-depth samplings.

These original maps were evaluated by the author by random spot checks of depth and location, and were found to be of good quality.

From the bathymetric maps of each lake certain morphometric parameters were obtained. These parameters, following definitions by Hutchinson (1957, p. 164-167), are summarized as follows:

Surface area (A). The area of the lake's surface, as determined by planimetry from the outline of the lake. When defining area-depth relationships, the lake-surface area is determined at more than one lake stage or surface elevation, usually in feet above msl (mean sea level).

Lake volume (V). The volume, obtained by computing, then summing the volume of a series of water elements extending vertically from the lake bottom to the surface. The lake volume at a selected elevation is given by the equation

$$V = \int_{0}^{m} A\,dz \quad ,$$

where the volume is determined from the bottom contour (0) to a lake stage contour (m) over depth increments (dz) between contours.

Mean depth ($\bar{Z}$). The mean lake depth, for a specified lake stage, is obtained by dividing the volume of the lake by its area, or

$$\bar{Z} = V/A \quad .$$

Maximum depth (Z_m). The difference between the bottom and the surface of the lake. Because maximum depth varies with changes in lake stage it is referred to a selected stage datum.

Length of shoreline (L). The distance around, or perimeter, of the water surface touching the shore at a specified lake stage. The length of shoreline may be determined for several different lake stages and a graph made of length of shoreline versus lake stage.

Length of lake (l). The shortest distance across the lake, between the two most distant points on the lakeshore. The length may be determined for any lake stage.

Breadth of lake (b). The greatest distance from shore to shore, normal to the line defining the length (l) of the lake.

Development of shoreline (D_L) or shoreline configuration. (Because of the inference of "Development of shoreline" the terminology used in this report will be shoreline configuration.) A dimensionless ratio of length of shoreline to the circumference of a circle having an area equal to that of the lake, given as

$$D_L = \frac{L}{2\sqrt{\pi A}} .$$

This quantity may be regarded as a measure of the littoral process on the lake, if the area is assumed not to change with time. D_L is always greater than unity.

Nearly circular lakes have values near unity, subcircular lakes have slightly greater D_L values and elongate lakes have the highest D_L values. Subcircular lakes are typical of lakes in relatively unconsolidated material which are easily remodeled by shore process. High D_L values exemplify lakes formed by kettle chains along old drainages or by the damming of streams to form a lake in the valley behind the dam.

Lakes which occupy compound kettle holes usually have D_L values between 1.5 and 2.0.

Development of volume (D_V) and the ratio of mean depth to maximum depth ($\bar{Z}/Z_m$). A dimensionless ratio of the volume of the lake to that of a cone having a base area equal to the surface area (A) of the lake and a height equal to the maximum depth (Z_m) of the lake:

$$D_V = 3\bar{Z}/Z_m .$$

D_V is a measure of the departure of the shape of the lake basin from that of a cone. Hutchinson (1957) has given $\bar{Z}/Z_m$ as a more convenient ratio and, for the purpose of comparable data, $\bar{Z}/Z_m$ values are given in this report.

A basin that has a volume less than that of a cone of basal area (A) and height (Z_m) is relatively rare. However, the $\bar{Z}/Z_m$ index tells nothing about the distribution of the deep areas in a lake and, therefore, the bathymetric maps must be consulted when comparing values between lakes.

Relative depth (Z_r). The maximum depth as a percentage of the mean diameter given as

$$Z_r = \frac{50\ Z_m \sqrt{\pi A}}{A} .$$

Mean slope (ϵ). The average slope of the lake bottom, approximated from

$$\tan \epsilon = \frac{(\frac{1}{2}L_o + L_1 + L_2 \cdots\cdots L_{n-2} + \frac{1}{2}L_{n-1}) Z_n}{nA} ,$$

where n is the number of horizontal slices chosen. Each slice is of equal thickness has a perimeter L_n on top and L_{n+1} on the bottom, the total depth used is Z, and area (A) is at L_o.

Generally, the water-temperature profiles of the lakes studied show total mixing during the winter--nearly uniform temperatures from top to bottom--and thermal stratification during the summer. Thermally stratified lake waters may be divided into: (1) epilimnion, the upper mixing part having fairly uniform warm temperatures; (2) thermocline, the two-dimensional surface (Hutchinson, 1957, p. 428) where water temperatures have a maximum rate of decrease; and (3) hypolimnion, the lower waters where the temperature is characteristically uniform and cooler than in the epilimnion and mixing is poor or nonexistent. Hutchinson (1957, p. 428) defines a fourth term, metalimnion, as the entire transition zone between the epilimnion and the hypolimnion which includes the thermocline. An example of water-temperature profiles is shown in figure 31 (p. 73).

For most of the lakes in this report, the profiles of DO concentration have generally the same shape as the temperature profiles. In summer, the DO profiles are of a shape referred to as a clinograde oxygen curve, as illustrated by the June and September DO profiles in figure 36. In most of the lakes studied the oxidative processes that occur in the

stagnant hypolimnion during summer stratification remove some or most of the oxygen in this zone, thus forming the clinograde curve. In addition, many of the lakes in western Washington have a summer clinograde oxygen curve which develops (usually in late summer) a positive heterograde distribution, with a metalimnetic zone where DO concentration is at a maximum. A decrease in oxygen saturation concentration caused by warming in the epilimnion, in conjunction with the development of a clinograde curve, may produce these maxima just below the epilimnion by purely physical processes. When really marked supersaturation is encountered it presumably is attributable to photosynthesis.

Of the 22 lakes investigated, only Merrill and Packwood Lakes had total ice cover during the winter. Because of the deep snow at the altitudes of these two lakes, access is extremely difficult even before they freeze, and no under-ice measurements were made.

As an aid in evaluating the actual profile of DO concentration, the profile for 100-percent oxygen saturation of the lake waters also is shown (for example, fig. 32). These saturated values of DO concentration were calculated from the water temperatures and altitude of the lake.

The Secchi-disc transparency depth, along with the positive heterograde oxygen distribution (Hutchinson, 1957, p. 620), is an index of the depth of light penetration into the water, or the transparency of the lake waters. The white disk, 10 centimeters in diameter, is lowered into the water until it just disappears and then is raised until it is just visible; this is taken as the depth of transparency.

Also obtained were profiles of specific conductance, an indicator of the total dissolved mineral solids present in the lake waters. These profiles were determined by using a temperature-compensated conductivity meter with the probe at the end of a 50-foot cable. The conductivity meter was only sensitive to conductance values equal to or greater than 40 micromhos per centimeter. Thus, the specific-conductance profiles in this report begin at 40 micromhos per centimeter and do not extend below the 50-foot depth.

The frequency of lake sampling was governed by the cycles of water mixing and stratification. Data were collected during (1) the winter mixing period, (2) spring, when thermal

stratification begins, (3) summer, at maximum thermal stratification, and (4) fall, shortly before mixing of the lake waters begins. One or more locations on the lake were selected to represent the limnetic conditions and enough vertical samples were taken to adequately define the profile.

To obtain a complete profile, samplings for DO (dissolved oxygen), water chemistry, temperature, and specific conductance were usually made at the deepest part of the lake. However, samples and check samples were made at other, shallower, locations to confirm the horizontal consistency of these parameters.

The seasonal fluctuations in lake stage were obtained by either (1) measuring from an established reference point each time the lake was visited, (2) having a local resident make observations by reading a staff gage set at some datum, or (3) obtaining the lake-stage changes from a recording gage.

Measurements of surface-water inflows and outflows were made by standard U.S. Geological Survey methods at the time of each visit to the lakes. The surface-water outflows of some lakes were or are continuously monitored by Geological Survey stage-recording gages.

The chemical analyses of the lake waters, listed in this report, were performed by the Geological Survey.

Lake-Numbering System

The lakes are listed in this report in accordance with a numbering system used nationwide by the Geological Survey to designate data-collection stations in stream basins. Each lake has a unique number which, like the lake name, is a means of identification. The first two digits of the number indicate the region or "part," such as part 12 (see fig. 2). These are followed by a six-digit lake-station number representing the position of the surface outlet (or, if the lake has no outlet, the southernmost tip). In relation to nearby stream-station numbers, the lakes are listed in downstream direction along the main drainage system, and lakes on tributaries are listed between lakes on the main stream system in the order in which those tributaries enter the main system.

SUMMARY AND INTERPRETATION

Of the 3,813 lakes in western Washington listed by Wolcott (1965), it is obvious that the 22 lakes investigated in this report are only a small sample of the total population. However, these lakes were selected for their geologic, physiographic, and geographic settings as being generally representative of the physical characteristics of almost the entire population of western Washington lakes.

Continental and alpine glaciation accounts for the origin of the majority of the lakes in western Washington. Eighteen of the lakes studied occupy kettles (depressions in glacial deposits resulting from melting of residual ice from glaciers), three are in glacially modified valleys that subsequently have been naturally dammed and one occupies a valley eroded into its present form by glacial melt water. Approximately two-thirds of the lakes included in this study have maximum depths between 20 and 70 feet.

Glaciofluvial material, lava flows and related volcanic and other igneous deposits, and some terrace and marine deposits constitute most of the geologic units underlying the lake basins. The soils covering these deposits are composed of gravel, sand, silt, clay, loam and--in the Packwood Lake basin--some ashy soils.

The lake basins range from natural wilderness areas to areas of second-growth forests, farms, and urban development. The vegetal cover consists of varying amounts of conifer and deciduous trees, native underbrush, and grasslands. Basin populations range from fairly dense for Steilacoom Lake, to only one dwelling for Forest Lake.

Some selected physical and chemical characteristics for the 22 lakes studied are summarized in table 1. For comparison, the average, median, maximum, and minimum values are shown in the table. The average is the summation of the values of a parameter divided by the number of lakes, whereas the median is the 50-percent value, half the values being above and half being below the median value. Many of the median values are smaller than the average, indicating that the average value is influenced by a few high values.

TABLE 1. – Summary of selected physical and chemical characteristics of lakes studied

Lake		Morphometry					Chemistry (winter mixing period)						Hypolimnion oxygen (O_2) condition	Percent of lake area covered by macrophytes
							Milligrams per liter							
Number	Name	Surface area (A), in millions of sq. ft.	Mean depth ($\bar{Z}$), in ft.	Maximum depth (Z_m), in ft.	Shoreline configuration (D_L)	Development of volume (D_V)	Bicarbonate (HCO_3)	Hardness (Ca-Mg)	Total phosphate (PO_4) as phosphorus (P)	Total nitrogen (N)	Color (Co-Pt units)	Specific conductance (μmhos/cm) at 25°C		
12064000	Mission	3.82	11.5	25	1.45	0.56	34	28	0.006	0.4	0	68	Partial O_2 depletion in summer	1.3
066500	Panther	4.49	13.2	25	1.25	.53	10	7	.006	.2	0	20	Partial O_2 depletion in summer	.02
070455	Island	2.03	17.3	35	1.55	.49	13	13	.023	.4	10	44	O_2 depleted in summer	7.2
071000	Wildcat	5.28	18.5	33	1.45	.58	21	17	.013	.3	5	48	O_2 depleted in summer	.3
071500	Kitsap	10.8	18.1	29	1.22	.62	42	35	.016	.4	5	86	O_2 depleted in summer	2.2
072675	Crescent	2.16	15.8	29	1.40	.54	17	19	.013	.6	50	53	O_2 depleted in summer	4
073585	Jackson	.74	15.4	30	1.16	.51	11	10	.023	.3	40	29	O_2 depleted in summer, partial depletion in winter	16
087300	Clear	7.05	37.8	85	1.17	.45	21	16	.020	.2	0	53	O_2 depletion in summer	1.3
087400	Ohop	10.0	16.6	25	2.15	.66	18	21	.036	.4	30	70	O_2 depletion in summer	3
088300	Silver	6.49	12.0	22	1.01	.54	34	28	.013	.4	60	85	O_2 depletion in summer	2.3
088900	Tanwax	7.41	19.7	30	1.51	.65	30	24	.026	.5	50	71	O_2 depletion in summer	1.1
089200	Harts	5.27	25.8	50	1.04	.52	62	52	.20	1.1	50	134	O_2 depletion in summer, partial depletion in winter	11
090300	American	49.4	53.0	92	2.49	.59	48	42	.013	.04	5	107	O_2 depletion in summer	.07
090690	Gravelly	6.96	37.5	55	1.18	.68	62	54	.026	.77	5	146	O_2 depletion in summer, partial depletion in winter	.0
090990	Steilacoom	13.8	11.1	20	2.28	.56	43	42	.006	.93	10	112	O_2 depletion in summer	.01
093505	Forest	.27	12.4	38	1.37	.36	39	29	.052	.43	30	79	O_2 depletion in summer and winter	.0
110002	Wilderness	3.00	20.8	38	1.53	.54	32	28	.020	.18	5	70	O_2 depletion in summer, partial depletion in winter	.4
110004	Pipe	2.39	26.5	65	1.64	.41	19	17	.013	.11	20	52	O_2 depletion in summer	1.9
110005	Lucerne	.78	17.5	37	1.17	.47	19	17	.026	.14	10	53	O_2 depletion in summer, partial depletion in winter	5.1
142295	Hancock	10.7	25.4	36	1.25	.70	8	6	.016	.27	10	17	Partial O_2 depletion in summer	1.8
14222960	Merrill	21.3	38.4	77	2.04	.50	12	10	.010	.02	0	32	Only small O_2 depletion summer or winter	.0
225400	Packwood	17.6	70.8	117	1.50	.61	28	23	.026	.02	5	53	Only minor O_2 depletion summer or winter	.4
	Average	8.8	24.3	45	1.50	.55	28	24	.027	.37	18	67		
	Median	5.3	18.2	35	1.48	.54	21	21	.018	.35	10	52		
	Maximum	49.4	70.8	117	2.49	.68	62	54	.20	1.1	60	146		
	Minimum	.27	11.1	20	1.01	.36	8	6	.006	.02	0	17		

The shorelines of both Silver and Harts Lakes are nearly circular and show nearly equal erosion and (or) aggradation on all sides as denoted by shoreline configuration (D_L) values near unity. Gravelly Lake, located in relatively unconsolidated material which also is easily remodeled by geohydrologic processes, may be classified as a subcircular lake with its D_L value slightly greater than unity. American Lake, Steilacoom Lake, and Ohop Lake may be termed elongate lakes, based on their high D_L values. Shoreline configuration of these lakes was influenced by the valleys in which they were formed. American and Steilacoom Lakes are part of a chain of kettle lakes and Ohop Lake is in a valley deeply cut by a large glacial melt-water stream.

None of the lakes studied are characterized by a development of volume as small as that of a perfect cone ($\bar{Z}/Z_m$ value of 0.33). However, Forest Lake approaches this value ($\bar{Z}/Z_m = 0.36$), and may have been formed as a sublacustrine kettle in the floor of a once-larger lake. In addition, Forest Lake serves as an example of the affect of shape (low $\bar{Z}/Z_m$ value) on the mixing processes of the lake waters. Although most lakes show complete mixing during the winter, Forest Lake has an oxygen deficiency in the hypolimnion during the entire year (fig. 62), indicating incomplete mixing.

The majority of the lakes studied have annual changes of stage of only a few feet. Merrill Lake is the exception, with observations in 1970 showing lake-stage fluctuations of as much as 35 feet which is a change in volume of 560 million cubic feet (fig. 78).

All 22 lakes had some temperature stratification during the summer months, with 19 showing excellent stratification beginning in the spring and extending into the fall. Mission, Panther, and Merrill Lakes showed fair stratification, but with complex profiles and some mixing to within a few feet of the bottom.

Typical summer clinograde oxygen curves were exhibited by 16 of the 22 lakes. The curve begins in the epilimnion with near oxygen saturation and approaches zero oxygen concentration in the hypolimnion or stagnant region. Mission, Panther, and to some extent Kitsap Lakes approached zero oxygen concentration just a few feet from the bottom and only there presumably because of oxygen uptake by the bottom muds. Hancock Lake showed a deep zone of relatively high oxygen

concentration to about 10 feet from the bottom, even during maximum summer stratification. Oxygen profiles for Packwood and Merrill Lakes were complex, tending toward orthograde curves in the early summer and poor clinograde curves during late summer and fall.

Eight lakes developed a well-defined positive heterograde in the metalimnion of the clinograde oxygen profile. These positive heterograde developments with oxygen supersaturations were found in, and are summarized for, the following lakes:

Lake	Text figure	Date of observation	Percent oxygen saturation
Clear	32	6-16-70	118
		9- 5-69	123
Tanwax	43	9-12-69	114
American	51	6-30-70	120
Gravelly	55	7- 2-70	161
Steilacoom	59	6-30-70	140
Wilderness	66	6-24-70	133
Pipe	69	6-24-70	117
Lucerne	73	6-24-70	125

In these lakes, the depth of occurrence of the positive heterograde oxygen maxima coincides closely with the Secchi-disc transparency depths.

Slight metalimnion oxygen supersaturations were also observed in Island, Wildcat, and Kitsap Lakes during the period of maximum temperature stratification. However, these supersaturations probably were the result of physical processes rather than photosynthesis.

Generally, the mineral constituents of the lake waters did not change substantially from the winter mixing period to summer stratification. However, some constituents, such as silica, dissolved solids, iron, and manganese, showed an increase with depth during the stratification period. For most lakes, color and specific conductance also showed this increase with depth. Specific conductance, when measured near the bottom (at the mud-water interface) increased considerably, as would be expected because conductance is related to dissolved solids. Carbonate (CO_3) was zero for

all lakes sampled. Concentration of fluoride (F) changed little with time, depth or geographic location, having a range of 0 to 0.3 mg/l (milligram per liter).

The area of emergent macrophytes, given as a ratio of the area of plants to the total area of the lake, ranged from 0 to 16 percent (table 1). The dominant types of aquatic plants observed on the 22 lakes were:

Aquatic plant	Number of lakes where observed
Waterlily (Nuphar and (or) Nymphaea)	17
Pondweed (Potamogeton)	11
Waterweed (Elodea)	10
Sedge (Cyperus)	10
Cattail (Typha)	9
Watershield (Brasenia)	8
Bulrush (Scirpus)	5
Watercelery (Vallisneria)	4
Milfoil (Myriophyllum)	2
Horned pondweed (Zannichellia)	2
Muskgrass (Chara vulgaris)	2
Horsetail (Equisetum)	2
Buckbean (Menyanthes)	1
Water nymph (Najas)	1

Man's use of the lakes in western Washington has grown rapidly, especially within the last 10 years (based on recent field reconnaissance, notes from the Department of Game files, and house counts from topographic maps). Lakes are undergoing continuous physical, chemical, and biological changes in response to natural or cultural impositions. Unlimited use by man entails increased nutrient enrichment which in turn, accelerates lake eutrophication. It is difficult to predict how the recreational development and other uses of the lakes will affect various components of each lake's ecology. Certainly, some aspects of the lakes' environments will be altered. The degree of alteration will depend largely on the implementation of policies setting standards for allowable changes and rates of changes. It is hoped this study, and those that follow, will provide reference points that allow responsible agencies to estimate periodically the effects of population impact on the lakes in Washington.

REFERENCES

Basic-Data Publications

From the time of the first stream-measuring program in 1891, and through September 30, 1960, the records of surface-water discharge, and contents and stage of lakes and reservoirs, were published annually in a series of U.S. Geological Survey water-supply papers under the general title "Surface Water Supply of the United States." These reports consist of two series: (1) Compilation of Records of Surface Waters of the United States through September 1950, and (2) Compilation of Records of Surface Waters of the United States, October 1950 to September 1960. Each series has the following three parts, all or part of which pertain to Washington State:

1. Part 12. Pacific Slope Basins in Washington and Upper Columbia River Basin: Geological Survey Water-Supply Papers 1316 (through Sept. 1950) and 1736 (Oct. 1950 to Sept. 1960).

2. Part 13. Snake River Basin, Geological Survey Water-Supply Papers 1317 (through Sept. 1950) and 1737 (Oct. 1950 to Sept. 1960).

3. Part 14. Pacific Slope Basins in Oregon and Lower Columbia River Basin: Geological Survey Water-Supply Papers 1318 (through Sept. 1950) and 1738 (Oct. 1950 to Sept. 1960).

Beginning in the 1961 water year, basic surface-water data were released by the U.S. Geological Survey in annual reports which for 1961-64 were titled "Surface Water Records of Washington," and for 1965 to the present have been titled "Water Resources Data for Washington." These reports are available for examination at the Geological Survey's district office in Tacoma, Wash.

Beginning in the 1964 water year, the Geological Survey also published, by State, water-quality records for surface and ground water. These annual releases are for local and immediate use, but on a limited distribution only.

Other Selected References

Anderson, W. W., Ness, A. O., and Anderson, A. C., 1955, Soil survey of Pierce County, Washington: U.S. Dept. Agriculture Soil Survey Rept., ser. 1939, no. 27, 88 p.

Cunningham, R. K., and Pine, R. E., 1969, Preliminary investigation of the low dissolved oxygen concentrations that exist in Long Lake located near Spokane, Washington: Washington Pollution Control Comm. Tech. Rept. 69-1, 24 p.

Fassett, N. C., 1957, A manual of aquatic plants, with revision appendix by E. C. Ogden: Madison, University of Wisconsin Press, 405 p.

Goodwin, L. C., and Westly, R. E., 1967, Limnological survey of Kachess, Keechelus, and Cle Elum Reservoirs, a summary report: Washington Dept. Fisheries, Research Div. (duplicated) 72 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Washington Div. Mines and Geology, scale 1:500,000.

Hutchinson, G. E., 1957, A treatise on limnology, volume 1, Geography, physics and chemistry: New York, John Wiley & Sons, Inc., 1015 p.

Lee, R. A., 1969, Limnological studies of selected Washington State lakes: Washington Water Pollution Control Comm. Tech. Rept. 69-2, 55 p.

Luzier, J. E., 1969, Geology and ground-water resources of southwestern King County, Washington: Washington Dept. Water Resources Water-Supply Bull. 28, 239 p.

Molenaar, Dee, 1965, Geology and ground-water resources, in Garling, M. E., Molenaar, Dee, and others, 1965, Water resources and geology of the Kitsap Peninsula and certain adjacent islands: Washington Div. Water Supply Bull. 18, p. 24-50 and pl. 1.

Poulson, E. N., Miller, J. T., Fowler, R. H., and Flannery, R. D., 1952, Soil survey of King County, Washington: U.S. Dept. Agriculture Soil Survey Rept., ser. 1938, no. 31, 106 p.

Prescott, G. W., 1969, The aquatic plants: Pictured-key nature series: Dubuque, Wm. C. Brown Co., 171 p.

Rawson, D. S., 1939, Some physical and chemical factors in metabolism of lakes: Am. Assoc. Adv. Sci. Bull. 10, p. 9-26.

Sceva, J. E., 1957, Geology and ground-water resources of Kitsap County, Washington: U.S. Geol. Survey Water-Supply Paper 1413, 177 p.

U.S. Soil Conservation Service (no date), Soil Association Map, Columbia-North Pacific Comprehensive Framework Study, Puget Sound subregion 11, Map no. 7-P-18604-11C.

Walters, K. L., and Kimmel, G. E., 1968, Ground-water occurrence and stratigraphy of unconsolidated deposits, central Pierce County, Washington: Washington Dept. Water Resources Water Supply Bull. 22, 428 p.

Wildermuth, R., Perkins, S. O., Pasco, R. E., and Hubbard, E. H., 1939, Soil survey of Kitsap County, Washington: U.S. Dept. Agriculture Soil Survey Rept., ser. 1934, no. 12, 41 p.

Wolcott, E. E., 1965, Lakes of Washington, volume 1, Western Washington [2d ed.]: Washington Div. Water Resources Water Supply Bull. 14, 619 p.

12064000. Mission Lake near Bremerton

Location.--Surface-water outlet at lat 47°32'00", long 122°50'05"; lake in NW¼ sec.32 and S½ sec.29, T.24 N., R.1 W., Kitsap County.

Origin.--Kettle lake in glacial outwash deposits with the shape partly due to hill of volcanic rock to north.

Basin geology.--Glacial drift with volcanic rocks to north.

Soils.--Gravelly sandy loam soils on moderately steep slopes.

Land use and cover.--Forest and residential.

Forest cover consists of second-growth fir and, in the lower areas, deciduous trees including alder, balsam, poplar, and maple. About 20 acres were cleared on northwest side of lake as of 1971. Northeastern part of basin includes some swampland.

Population.--Lakeshore and nearshore dwellings number about 48 in 1971 (field canvass), as compared to about 20 in 1953 (estimated from U.S. Geological Survey topographic map); remainder of basin essentially unpopulated.

Physical features of lake.--Littoral zone of lake composed of gravel in matrix of sand, silt, clay, and muck.

Bathymetric map is shown in figure 3 (Wolcott, 1965, p. 208).

Some morphometric parameters, at a lake stage of 515.5 ft (msl), are:

Drainage area	1.83 sq mi	Length of shoreline	10,000 ft
Altitude of deepest part of lake (using msl datum)	491 ft	Length of lake	3,060 ft
Surface area	3.82 million sq ft	Breadth of lake	2,550 ft
Lake volume	44.0 million cu ft	Shoreline configuration	1.45
Mean depth	11.5 ft	Development of volume	0.56
Maximum depth	25 ft	Relative depth	0.9 percent
		Mean slope	2°32'

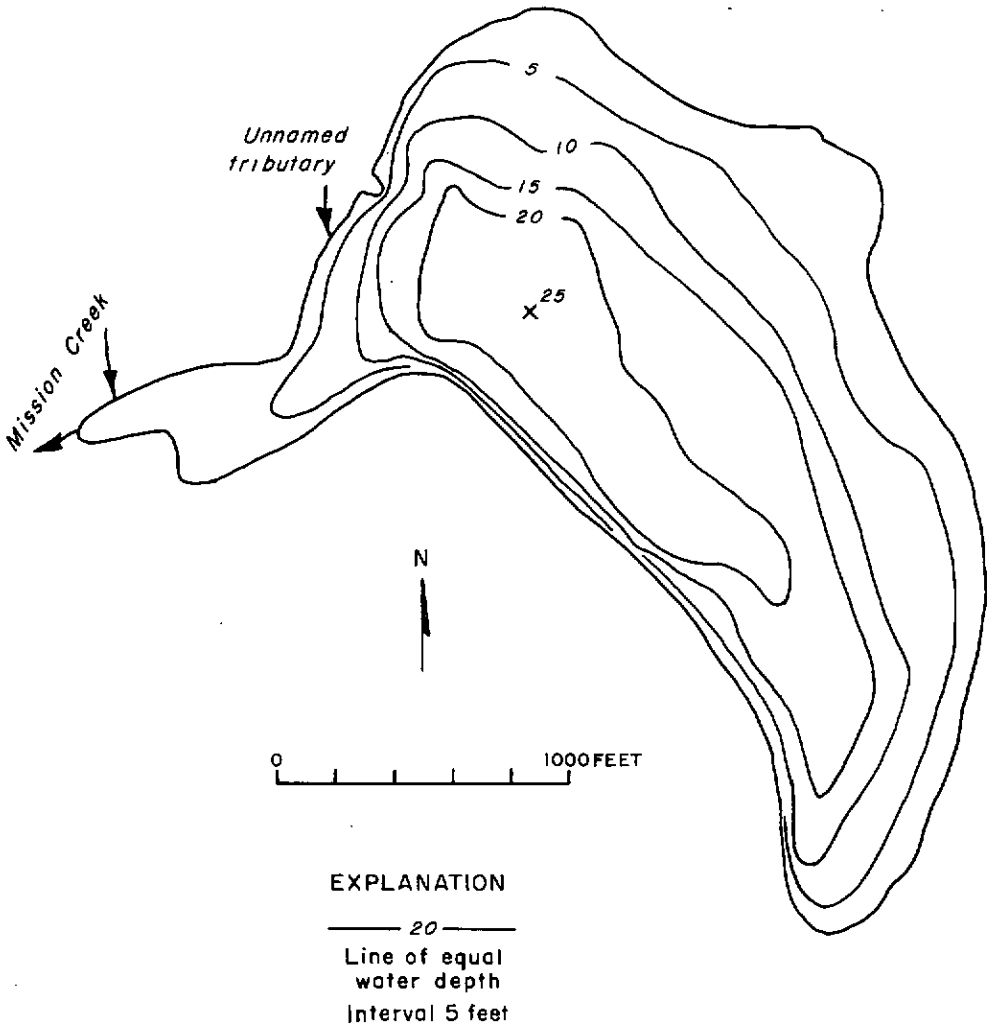


FIGURE 3. – Mission Lake near Bremerton, surveyed June 8, 1946 by State Department of Game (map. from Wolcott, 1965, p. 208). Zero-depth datum is 516 ft. (msl).

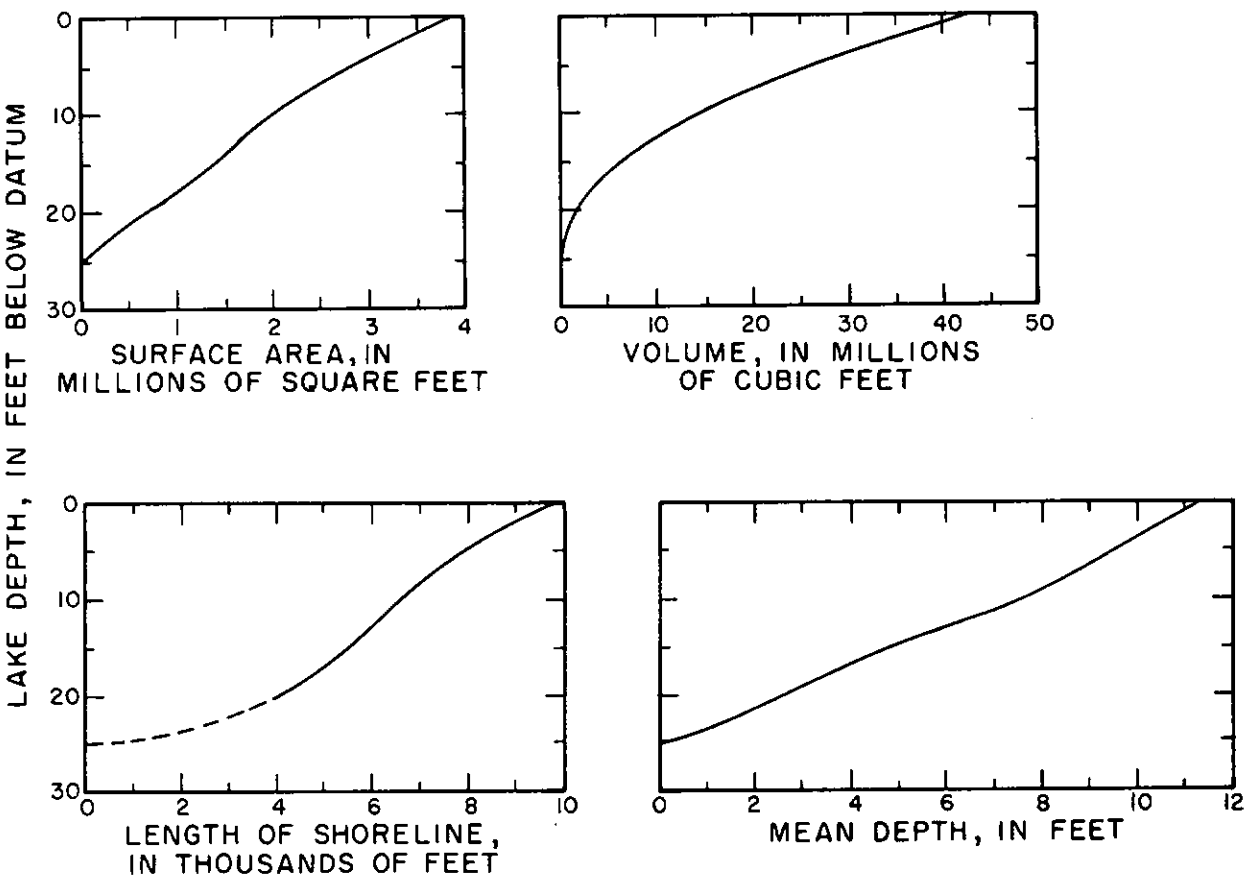


FIGURE 4. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Mission Lake near Bremerton. Zero-depth datum is 515.5 feet above mean sea level, based on topographic-map altitude.

Figure 4 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 5 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

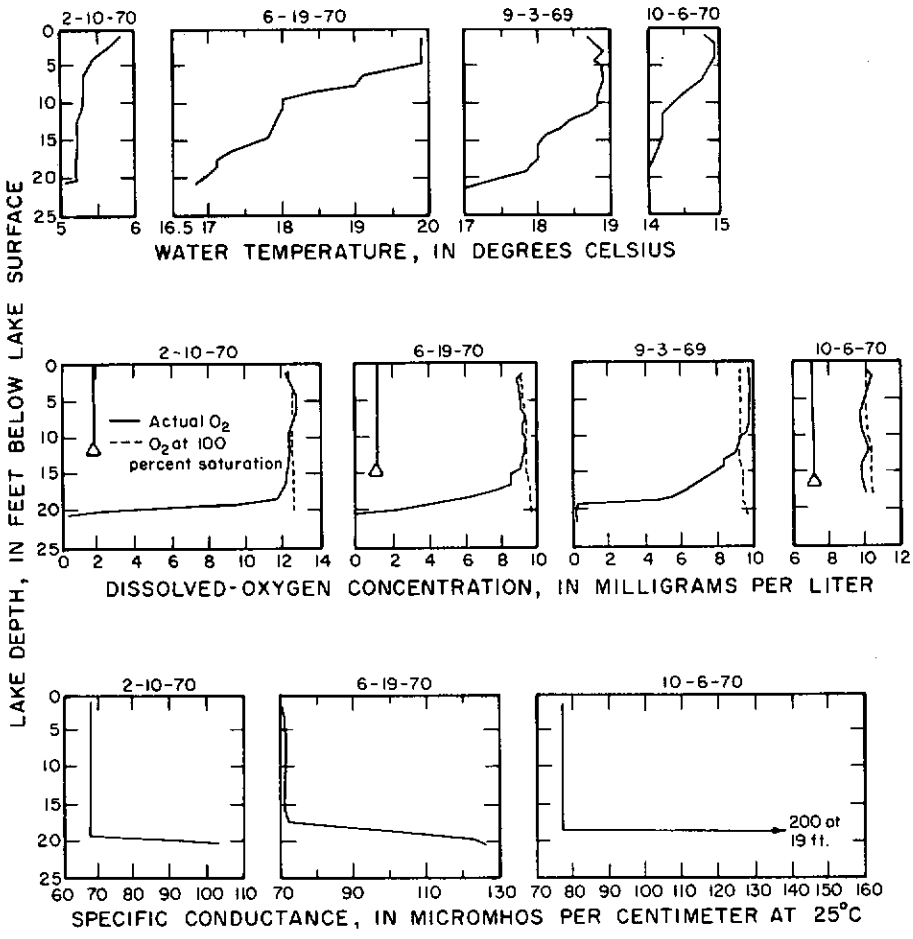


FIGURE 5. – Selected seasonal profiles of lake-water temperature, DO concentration, and specific conductance for Mission Lake near Bremerton, 1969-70. Secchi-disc transparency depths are indicated by base of triangles on DO profiles.

Lake stages.--Hydrograph of monthly maximum and minimum lake stages during 1946-52 shown in figure 6.

Miscellaneous measurements of lake stages, at mean sea level datum, are:

Date	Lake stage (in ft above msl)
9- 3-69	514.95
2-10-70	515.78
6-19-70	515.31
10- 6-70	514.96
10-23-70	515.41

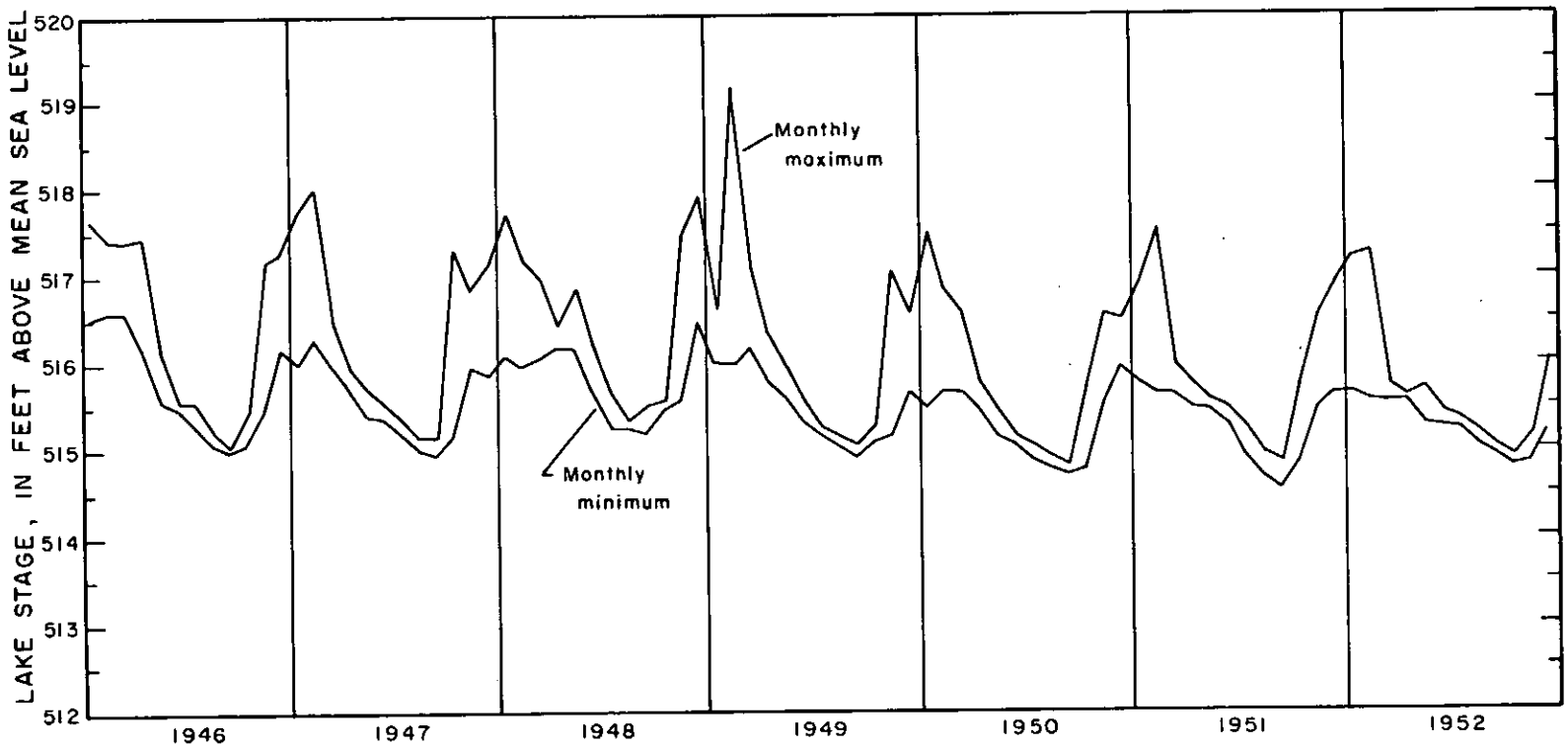


FIGURE 6. – Monthly maximum and monthly minimum lake stages, Mission Lake near Bremerton, 1946-52.

Surface-water inflow and outflow.--Mostly via Mission Creek.

A fish screen installed in outflow channel in 1949 has a slight regulatory effect on lake stage. Additional inflow comes from an unnamed tributary on northeast side which drains southwestern slopes of Gold Mountain, which is composed mostly of volcanic rocks.

A hydrograph of lake outflow (12064500. Mission Creek near Bremerton) is shown in figure 7 for the period 1946-52. Miscellaneous measurements of inflow and outflow are listed below. (Only measurements of outflow were made before 1969.)

Date	Inflow (in cfs)	Outflow (in cfs)
10-10-53	--	0
7- 2-58	--	0
7-24-58	--	0
8-13-58	--	0
6-22-59	--	0
7-17-59	--	0
8- 5-59	--	0
8-20-59	--	0
9- 3-69	0	0
3-10-70	0.10	6.6
6-19-70	0	.12
10- 6-70	0	0

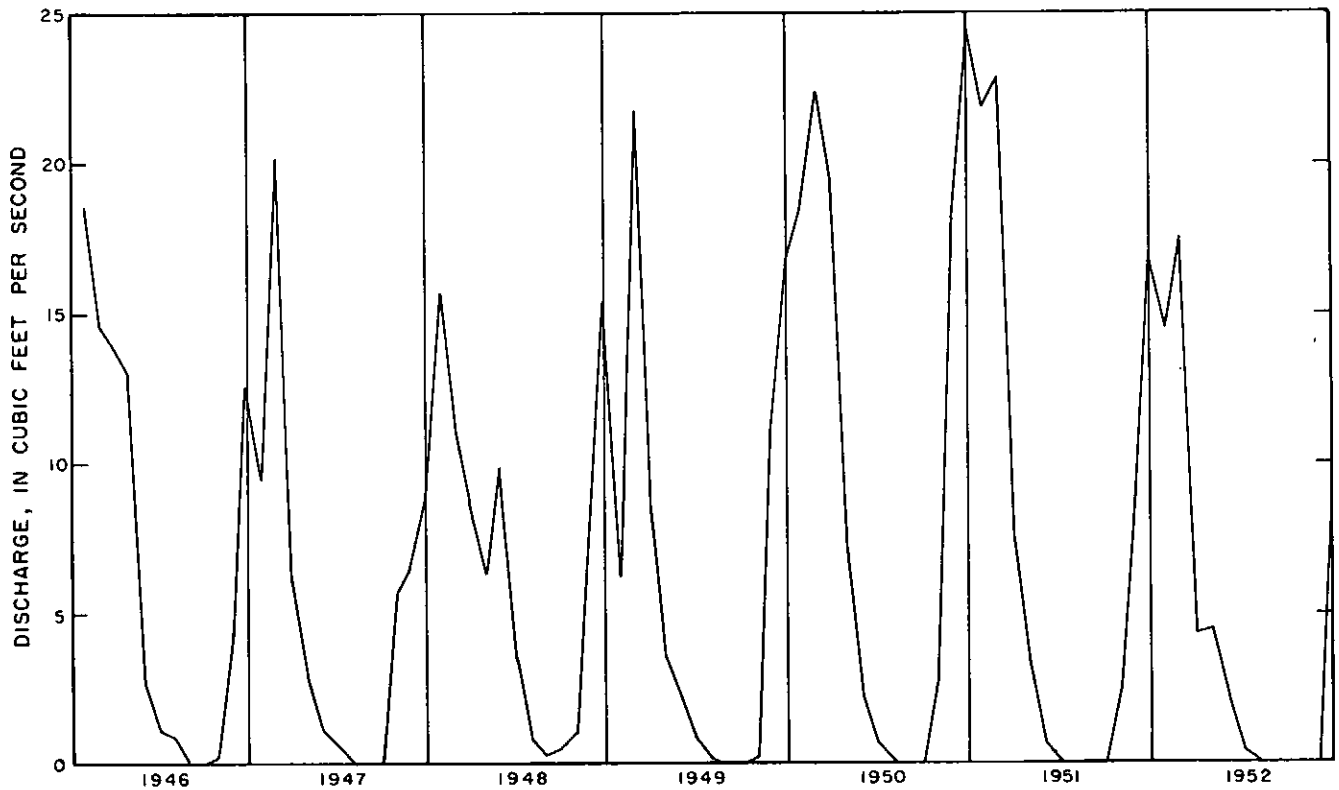


FIGURE 7. – Monthly mean outflow from Mission Lake (12064500. Mission Creek near Bremerton), 1946-52.

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-10-70	10-6-70
Depth of samples below surface, in ft	10	[a] 3,10,and 16
Silica (SiO_2)	16	0.3
Iron (Fe)	--	--
Manganese (Mn)	--	--
Calcium (Ca)	8.0	9.6
Magnesium (Mg)	2.0	2.4
Sodium (Na)	1.8	1.9
Potassium (K)	.2	.0
Bicarbonate (HCO_3)	34	44
Carbonate (CO_3)	0	0
Sulfate (SO_4)	2.4	.9
Chloride (Cl)	1.6	1.3
Fluoride (F)	.1	.1
Dissolved solids (residue at 180°C)	42	53
Hardness Ca-Mg	28	34
Hardness Noncarbonate	0	0
Alkalinity	28	36
pH, units	7.1	7.4
Color, Co-Pt units	0	5

[a] Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 5.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 3-69	1	0.003	0.016	0.00	--	--	--	0.07
2-10-70	10	.003	.006	.07	--	--	--	.40
6-19-70	18	.000	.003	.04	--	--	--	.09
10- 6-70	3	.003	.006	.20	0.000	0.02	0.07	.29
10- 6-70	10	.003	.003	.20	.000	.02	.10	.32
10- 6-70	16	.003	.006	.30	.000	.02	.17	.49

Macrophytes.--Area of macrophytes 1.3 percent of lake area, October 6, 1970.

The dominant macrophytes found were pondweed (Potamogeton), watershield (Brasenia), waterweed (Elodea), waterlily (Nuphar), bulrushes (Scirpus), sedge (Cyperus), and cattail (Typha). The aquatic weeds, although not extensive, appear to have a large diversity of broad-leaved species.

Conclusions.--Even though the number of lakeshore dwellings has almost tripled since 1953, and the lake has a shallow mean depth--both would favor biologic productivity--the biologic productivity of Mission Lake is low to medium. This productivity is evidenced by a low dissolved-solids content (thus a low specific conductance) and a low winter nutrient content, especially phosphorus. Mission Lake has slightly higher macrophyte production than other lakes in this vicinity.

12066500. Panther Lake near Bremerton

Location.--Surface-water outflow at lat 47°31'10", long 122°51'08"; lake in sec. 31, T.24 N., R.1 W., and sec. 6, T.23 N., R.1 W., Mason and Kitsap Counties.

Origin.--Kettle lake.

Basin geology.--Glacial drift.

Soils.--Gravelly sandy loam soils on moderate to steep slopes.

Land use and cover.--Forest, residential and recreational.

The basin is covered by forest with interspersed dwellings. About 90 percent of vegetal cover is second-growth fir and cedar with an understory of salal, huckleberry, and swordfern; remaining 10 percent, mainly low-lying areas, has deciduous trees, such as alder, madrona, dogwood, and willow.

Population.--House count of October 1970 noted 59 dwellings from 25 to 100 ft from water's edge, as compared to about 20 dwellings in 1953 and about 25 in 1968 (estimated from U.S. Geological Survey topographic maps).

Physical features of lake.--Littoral zone composed of coarse gravel; a 13,000-sq ft island in eastern part of lake.

Bathymetric map shown in figure 8 (Wolcott, 1965, p. 208).

Some morphometric parameters, at a lake stage of 498.6 ft (msl) are:

Drainage area	0.80 sq mi	Length of shoreline	9,380 ft
Altitude of deepest part of lake (using msl datum)	473.6 ft	Length of lake	2,840 ft
		Breadth of lake	2,540 ft
Surface area	4.49 million sq ft	Shoreline configuration	1.25
Lake volume	59.4 million cu ft	Development of volume	0.53
Mean depth	13.2 ft	Relative depth	1.04 percent
Maximum depth	25 ft	Mean slope	2°08'

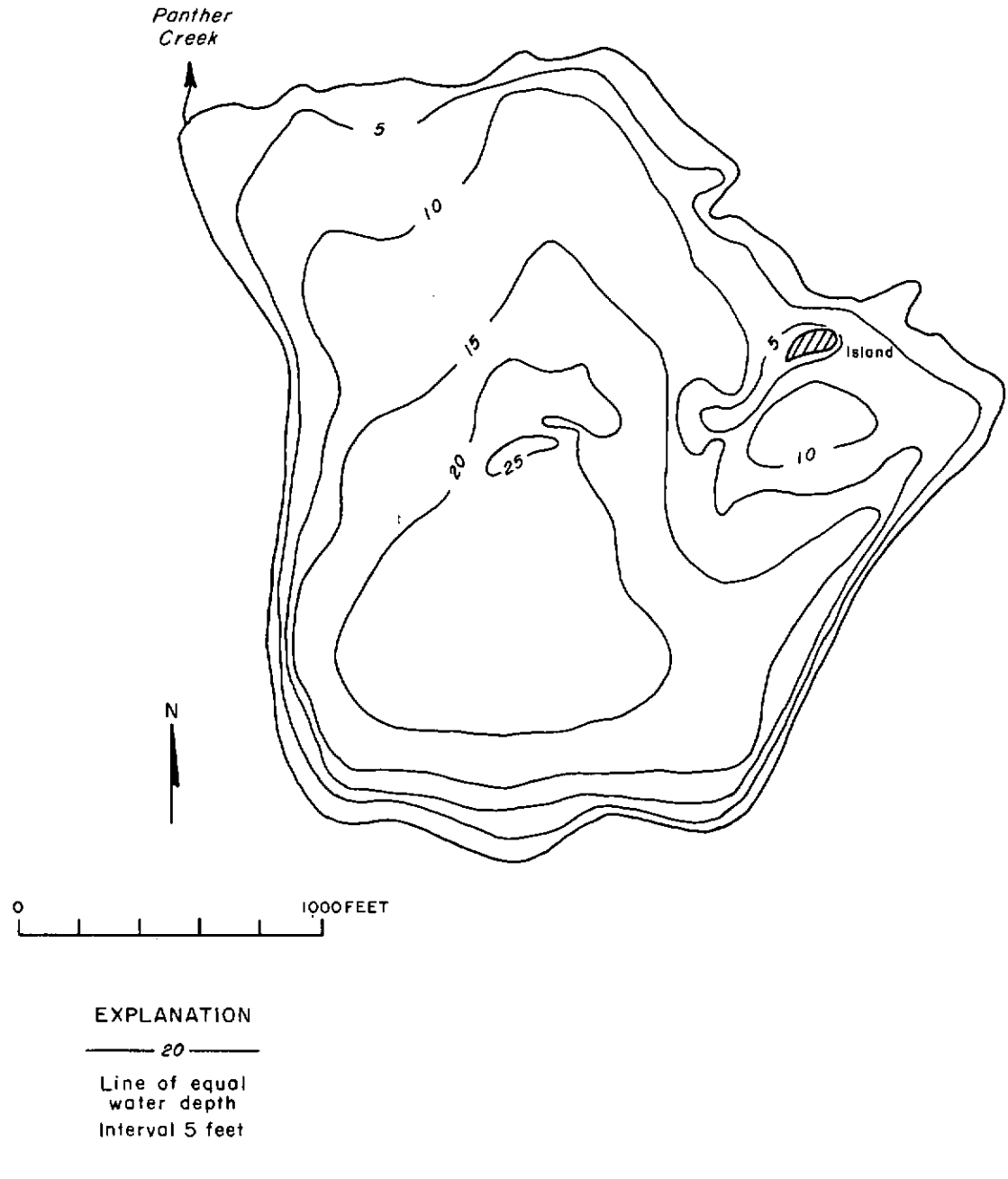


FIGURE 8. – Panther Lake near Bremerton, surveyed June 2, 1949 by State Department of Game (map from Wolcott, 1965, p. 208). Zero-depth datum is 497 ft. (msl).

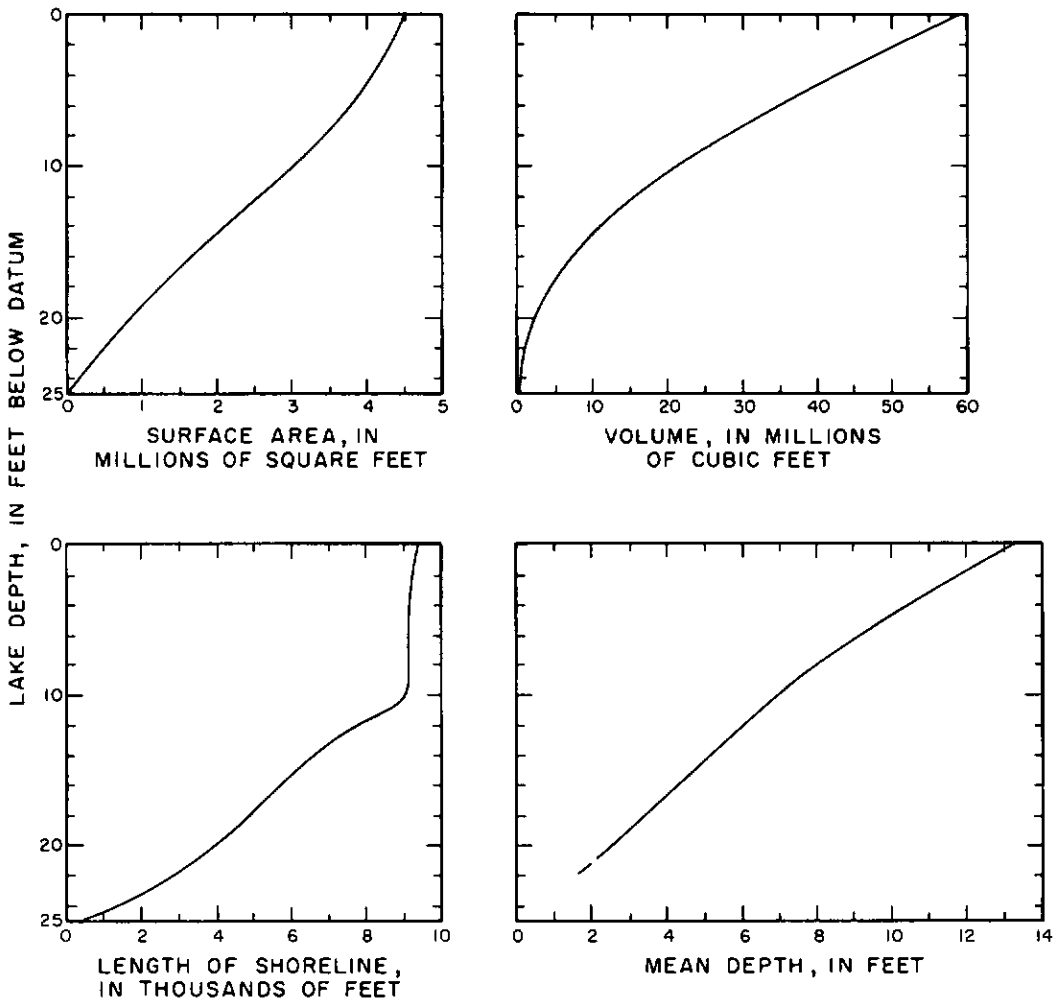


FIGURE 9. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Panther Lake near Bremerton. Zero-depth datum is 498.6 feet above mean sea level, based on topographic-map altitude.

Figure 9 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 10 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths. The specific conductance of the lake waters was found to be less than 40 µmhos/cm for all depth profiles.

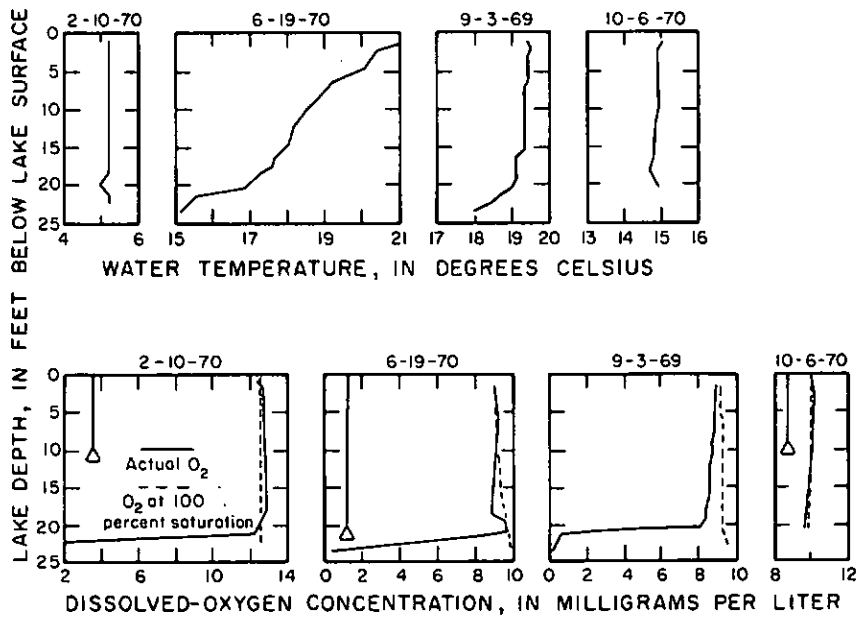


FIGURE 10. – Selected seasonal profiles of lake-water temperature and DO concentration, Panther Lake near Bremerton, 1969-70. Secchi-disc transparency depths are indicated by base of triangles on DO profiles.

Lake stages.--Hydrograph of annual observed maximum and minimum lake stages during 1945-53 shown in figure 11.

Using the same datum as that for 1945-53 (498.6 ft), the following stage observations were made:

Date	Lake stage (in ft above msl)
9- 3-69	497.76
2-10-70	499.00
6-19-70	498.42
10- 6-70	497.34
10-26-70	497.66

Surface-water inflow and outflow.--Inflow channel nonexistent.

Inflow is from precipitation, storm runoff, and ground water. Surface-water outflow was gaged (12067000. Panther Creek near Bremerton) from June 1945 to September 1953 and during this recent study the following outflow measurements were made.

Date	Outflow (in cfs)
9- 3-69	0.0
2-10-70	2.19
6-19-70	.05
10- 6-70	.0

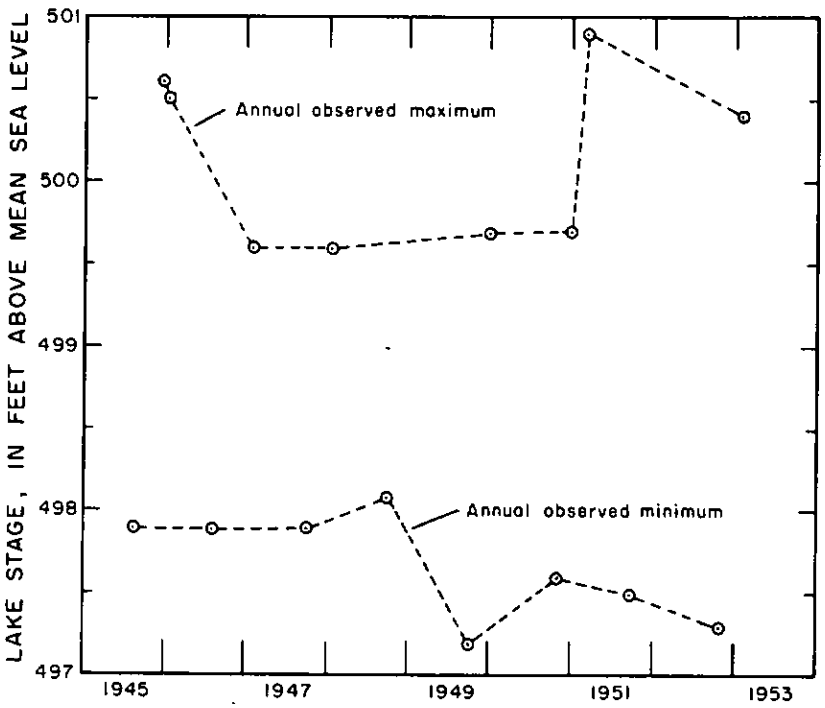


FIGURE 11. – Annual observed maximum and minimum lake stages, Panther Lake near Bremerton, 1945-53. Annual values are based on an average of 9.3 observations per year.

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-10-70	10-6-70
Depth of samples below surface, in ft	11	[a]3,10, and 17
Silica (SiO_2)	2.8	0.9
Iron (Fe)	--	--
Manganese (Mn)	--	--
Calcium (Ca)	1.5	1.2
Magnesium (Mg)	.7	.7
Sodium (Na)	1.1	1.3
Potassium (K)	.2	.1
Bicarbonate (HCO_3)	10	9
Carbonate (CO_3)	0	0
Sulfate (SO_4)	.2	.2
Chloride (Cl)	1.4	1.1
Fluoride (F)	.0	.0
Dissolved solids (residue at 180°C)	19	32
Hardness Ca-Mg	7	6
Hardness Noncarbonate	0	0
Alkalinity	8	7
pH, units	6.7	6.8
Color, Co-Pt units	0	5
Specific conductance, μmhos/cm	20	22

[a]Averages for three samples; constituents did not vary significantly.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 3-69	1	0.003	0.006	0.00	--	--	--	0.20
2-10-70	11	.003	.006	.02	--	--	--	.20
6- 9-70	19	.003	.006	.04	--	--	--	.10
10- 6-70	3	.006	.013	.09	0.000	0.02	0.14	.26
10- 6-70	10	.006	.010	.07	.000	.05	.15	.30
10- 6-70	17	.020	.020	.00	.000	.02	.18	.20

Macrophytes.--Area of macrophytes 0.02 percent of lake area, October 6, 1970.

Of the very few aquatic plants found in the lake, the dominant was sedge (Cyperus).

Conclusions.--Panther Lake has low biologic productivity, as indicated by high oxygen content, low specific conductance, low winter nutrient concentrations, and a lack of macrophytes. The potential enrichment by fecundation of the lake is increasing--the number of lakeshore dwellings has increased almost threefold in 17 years. This potential, combined with a shallow mean depth and the probable slow flushing rate of the lake, may, in the future, tend to increase the biologic-productivity level and rate of lake eutrophication.

12070455. Island Lake near Keyport

Location.--Surface-water outflow at lat 47°40'42", long 122°39'32"; lake in south-central half of sec. 3, T.25 N., R.1 E., Kitsap County.

Origin.--Kettle lake in glacial drift.

Basin geology.--Glacial till, sand, and gravel.

Soils.--Sandy loam and fine loamy sand on moderate to steep slopes.

Land use and cover.--Mainly residential and recreational.

Except for small cleared, grass-covered areas near lake, basin generally covered by second-growth fir and cedar with patches of deciduous trees, chiefly alder.

Population.--House count of October 1970 noted 26 private homes on east shore, Bible camp at south end, and resort at north end, as compared to about 18 lakeshore dwellings in 1953 (estimated from U.S. Geological Survey topographic map).

Physical features of lake.--Small island near southwest corner of lake; littoral zone of lake predominantly muck, silt, and sand with some gravel.

Bathymetric map shown in figure 12 (Wolcott, 1965, p. 214).

During the sampling period, the greatest depth found at the lake stages measured was 26 ft.

Drainage area	0.71 sq mi	Length of shoreline	7,820 ft
Altitude of deepest part of lake (using msl datum)	182 ft	Length of lake	2,520 ft
		Breadth of lake	1,370 ft
		Shoreline configuration	1.55
Surface area	2.03 million sq ft	Development of volume	0.49
Lake volume	35.1 million cu ft	Relative depth	2.2 percent
Mean depth	17.3 ft	Mean slope	4°54'
Maximum depth	35 ft		

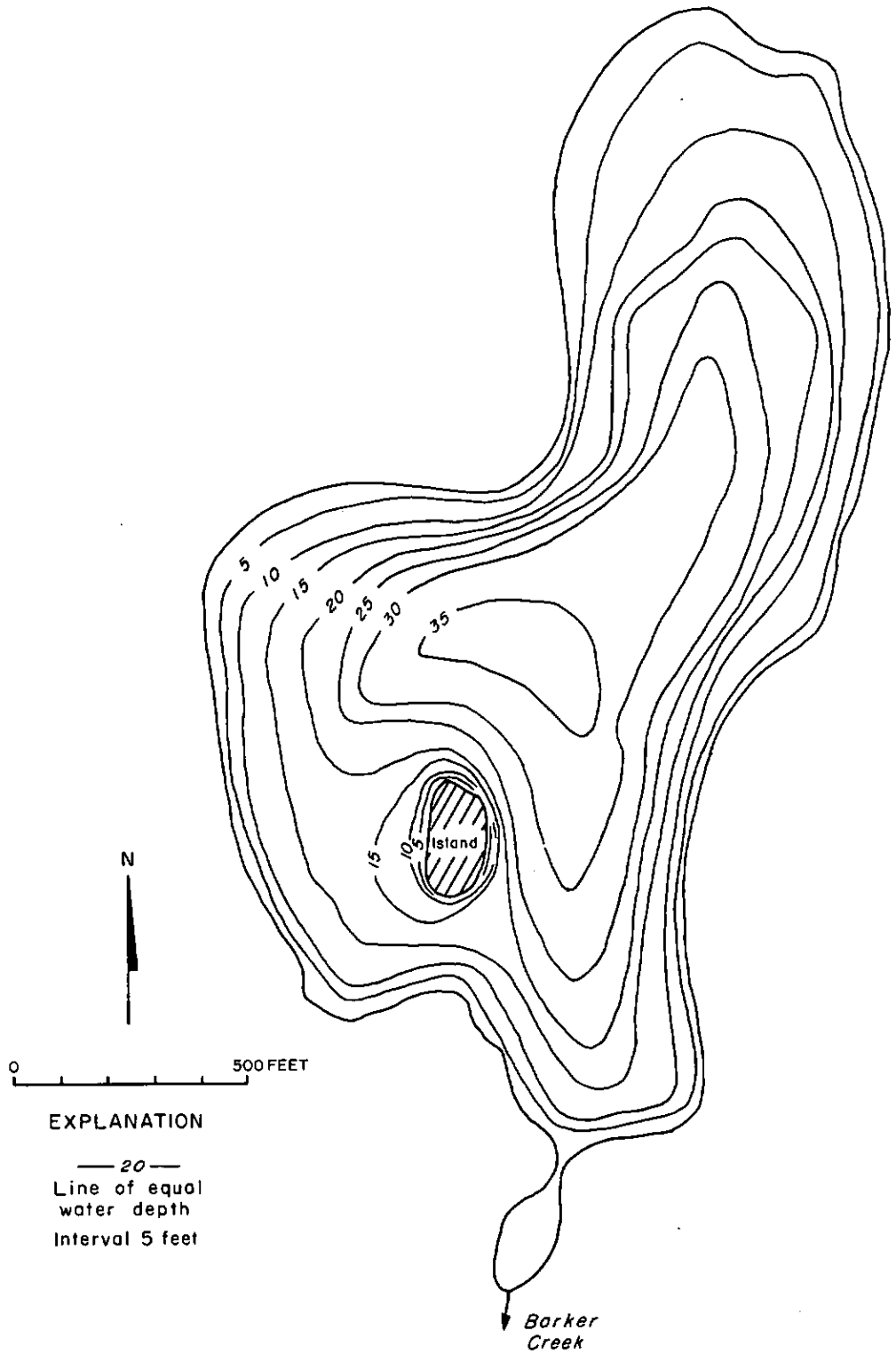


FIGURE 12. – Island Lake near Keyport, surveyed July 19, 1955 by State Department of Game (map from Wolcott, 1965, p. 214). Zero-depth datum is 217 ft. (msl).

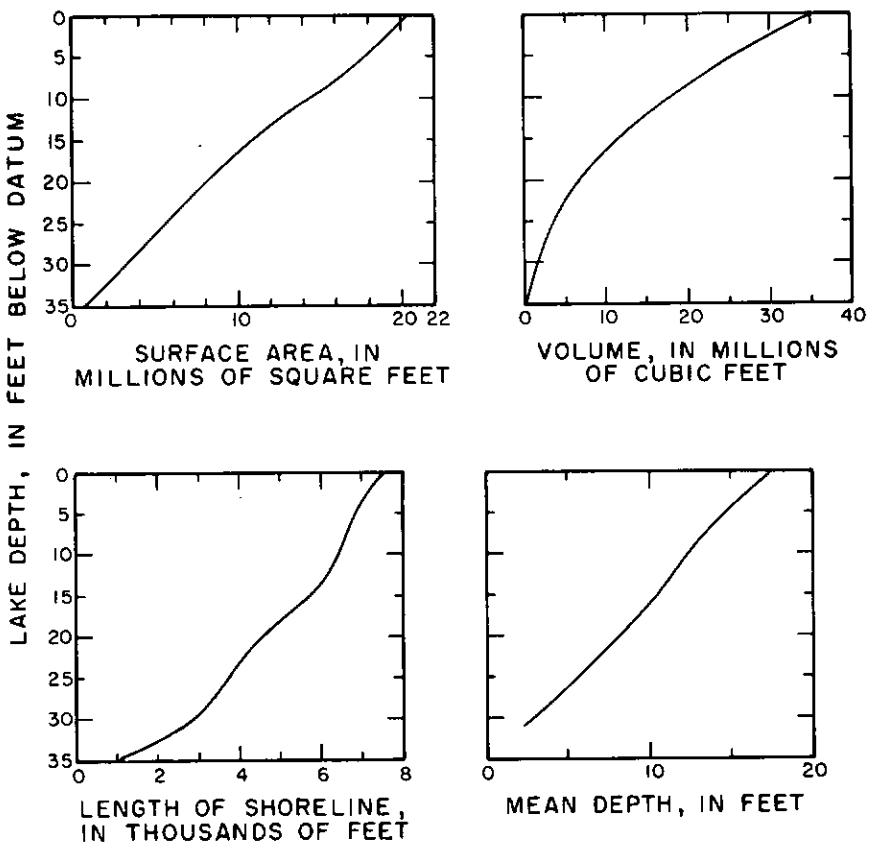


FIGURE 13. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Island Lake near Keyport. Zero-depth datum is 217 feet above mean sea level, based on topographic-map altitude.

Figure 13 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 14 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

Lake stages.--Outlet dammed and a valved 12-inch vertical pipe serves as outlet.

The lake will spill at a stage of 228.1 ft (top of pipe) or drainage is possible above a stage of 225.6 ft by opening the valve in the vertical pipe. Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9- 4-69	226.6
2- 9-70	227.9
6-23-70	227.3
10- 8-70	225.9
10-27-70	226.1

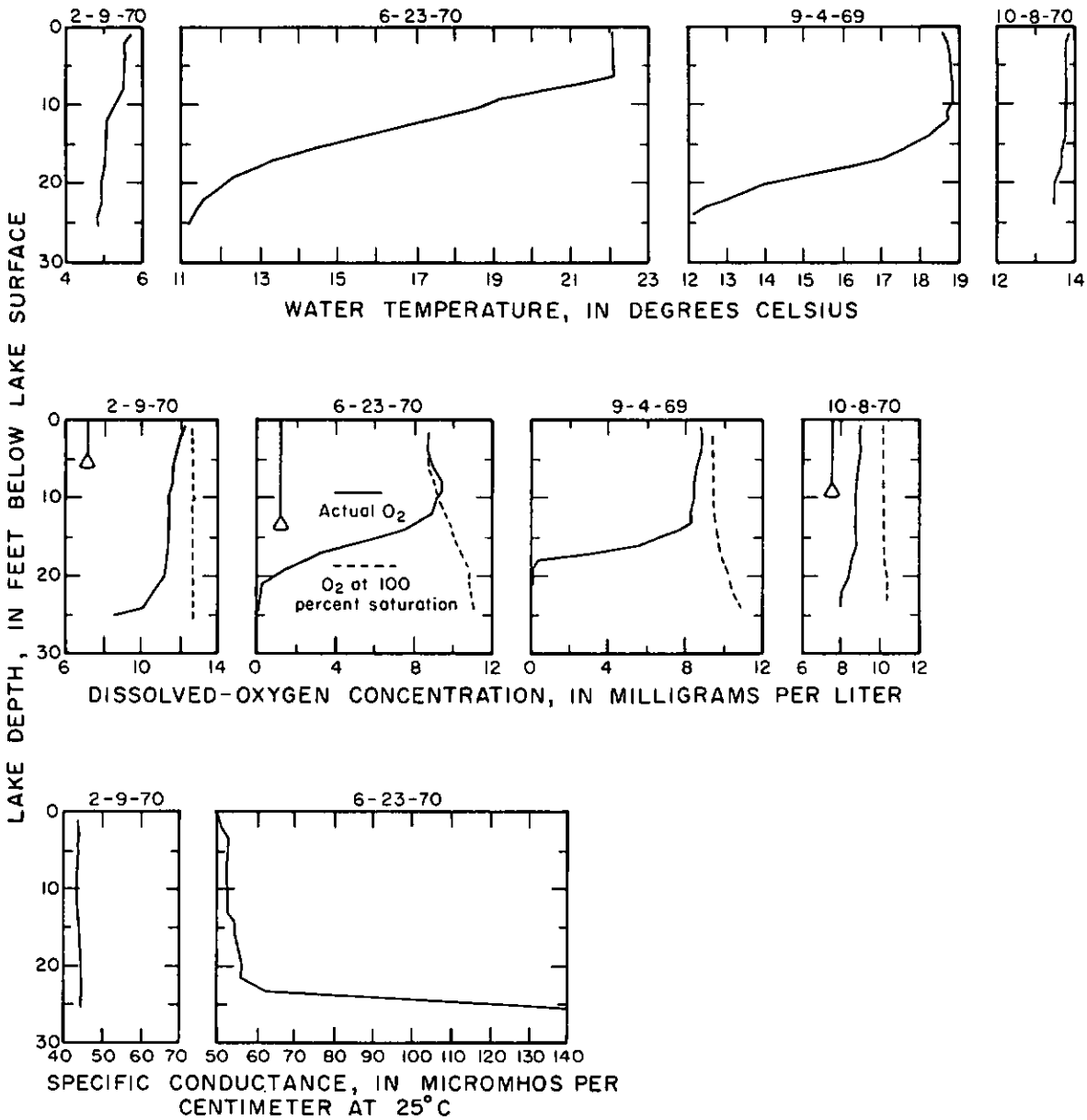


FIGURE 14. – Selected seasonal profiles of lake-water temperature, DO concentration, and specific conductance, Island Lake near Keyport, 1969-70. Secchi-disc transparency depths are indicated by base of triangles on DO profiles. During the October sampling the specific conductance values were less than 40 μmhos/cm over the entire profile. DO profiles for June 23 show very slight positive heterograde development.

Surface-water inflow and outflow.--Outflow via Barker Creek.

Inflow is from precipitation, ground water, and storm runoff. No outflow was observed during the five visits made to the lake.

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-9-70	10-8-70
Depth of samples below surface, in ft	17	[a] 3,10, and 20
Silica (SiO_2)	2.1	1.1
Iron (Fe)	--	.15
Manganese (Mn)	--	.03
Calcium (Ca)	2.9	2.8
Magnesium (Mg)	1.4	1.5
Sodium (Na)	2.5	2.9
Potassium (K)	.5	.4
Bicarbonate (HCO_3)	13	17
Carbonate (CO_3)	0	0
Sulfate (SO_4)	3.4	4.6
Chloride (Cl)	3.2	2.9
Fluoride (F)	.1	.1
Dissolved solids (residue at 180°C)	35	38
Hardness Ca-Mg	13	13
Hardness Noncarbonate	3	0
Alkalinity	11	14
pH, units	6.8	6.8
Color, Co-Pt units	10	10

[a] Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 14.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 4-69	1	0.003	0.010	0.00	--	--	--	0.20
2- 9-70	17	.003	.023	.07	--	--	--	.40
6-23-70	22	.000	.010	.04	--	--	--	.30
10- 8-70	3	.000	.013	.02	0.000	0.06	0.21	.27
10- 8-70	10	.000	.010	.04	.000	.07	.17	.24
10- 8-70	20	.000	.010	.04	.000	.05	.16	.21

Macrophytes.--Area of macrophytes 7.2 percent of lake area, October 8, 1970.

The dominant aquatic plant was watershield (Brasenia), followed by waterlily (Nymphaea), and minor patches of sedge (Cyperus) and watercelery (Vallisneria).

Conclusions.--Both natural and cultural sources of enrichment are included in Island Lake's environment. Development around the lake has not changed significantly in the past 17 years and the natural eutrophication rate of the lake probably is relatively high. The moderately high specific conductance of the water, the hypolimnion--oxygen deficit in summer, the moderate nutrient concentration during the winter mixing period, the low lake transparency, and the abundance of macrophytes all attest to the moderate to high biologic productivity of the lake.

12071000. Wildcat Lake near Bremerton

Location.--Surface-water outflow (Wildcat Creek) at lat 47°35'59", long 122°45'35"; lake in sec. 2, T.24 N., R.1 W., Kitsap County.

Origin.--Kettle lake.

Basin geology.--Glacial till and recessional outwash deposits with some volcanic rocks in southwestern part of basin.

Soils.--Gravelly and sandy loam soils on moderately to steeply sloping fans.

Land use and cover.--Forest and residential.

There is an airplane-landing strip and a resort on lakeshore. Vegetation is predominantly second-growth fir intermingled with cedar, alder, madrona, dogwood, and willow trees. The understory vegetation includes salal, huckleberry and fern.

Population.--Lakeside house count in October 1970 noted 75 structures from 25 to 75 ft from shore, as compared to about 60 lakeside homes in 1953 and about 70 in 1968 (estimated from U.S. Geological Survey topographic maps).

Physical features of lake.--Littoral zone of lake composed mainly of gravel and silt.

Bathymetric map shown in figure 15 (Wolcott, 1965, p. 207).

Some morphometric parameters, at a lake stage of 377 ft (msl), are:

Drainage area	2.50 sq mi	Length of shoreline	11,830 ft
Altitude of deepest part of lake (using msl datum)	344 ft	Length of lake	4,240 ft
Surface area	5.28 million sq ft	Breadth of lake	1,810 ft
Lake volume	97.6 million cu ft	Shoreline configuration	1.45
Mean depth	18.5 ft	Development of volume	0.58
Maximum depth	33 ft	Relative depth	1.23 percent
		Mean slope	2°38'

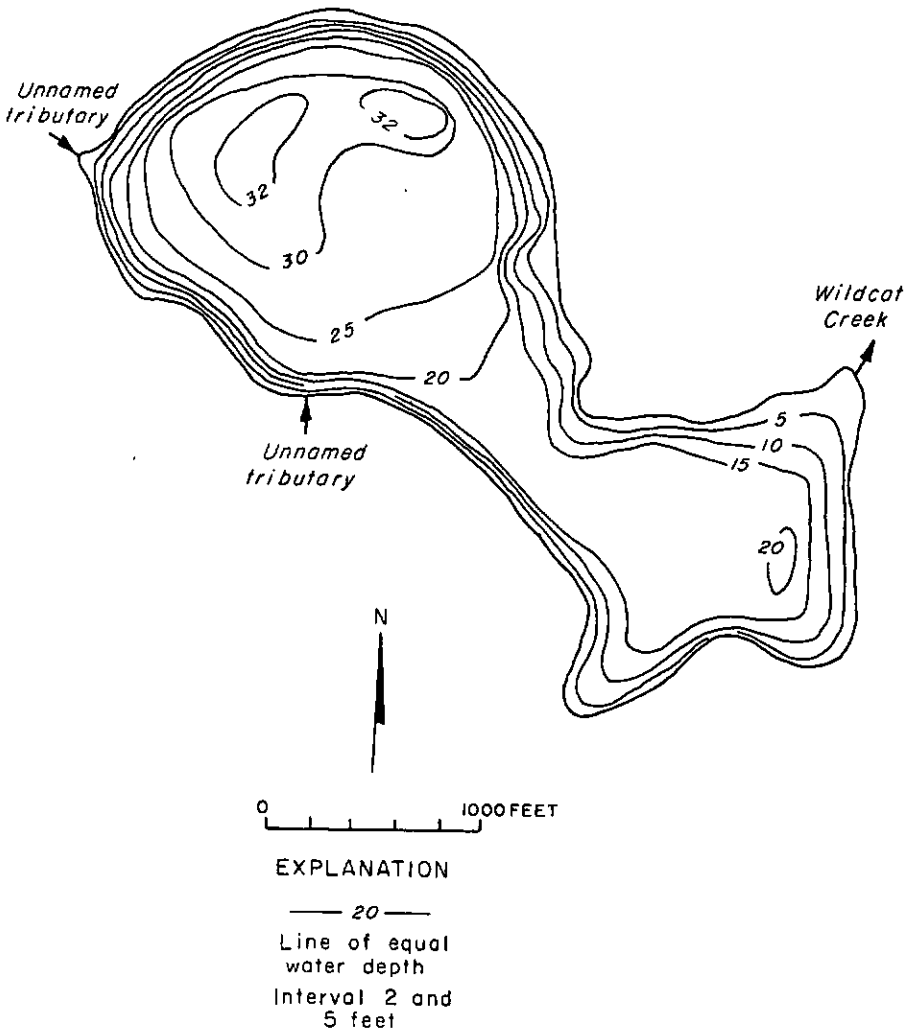


FIGURE 15. – Wildcat Lake near Bremerton, surveyed June 11, 1946 by State Department of Game (map from Wolcott, 1965, p. 207). Zero-depth datum is 377 ft. (msl).

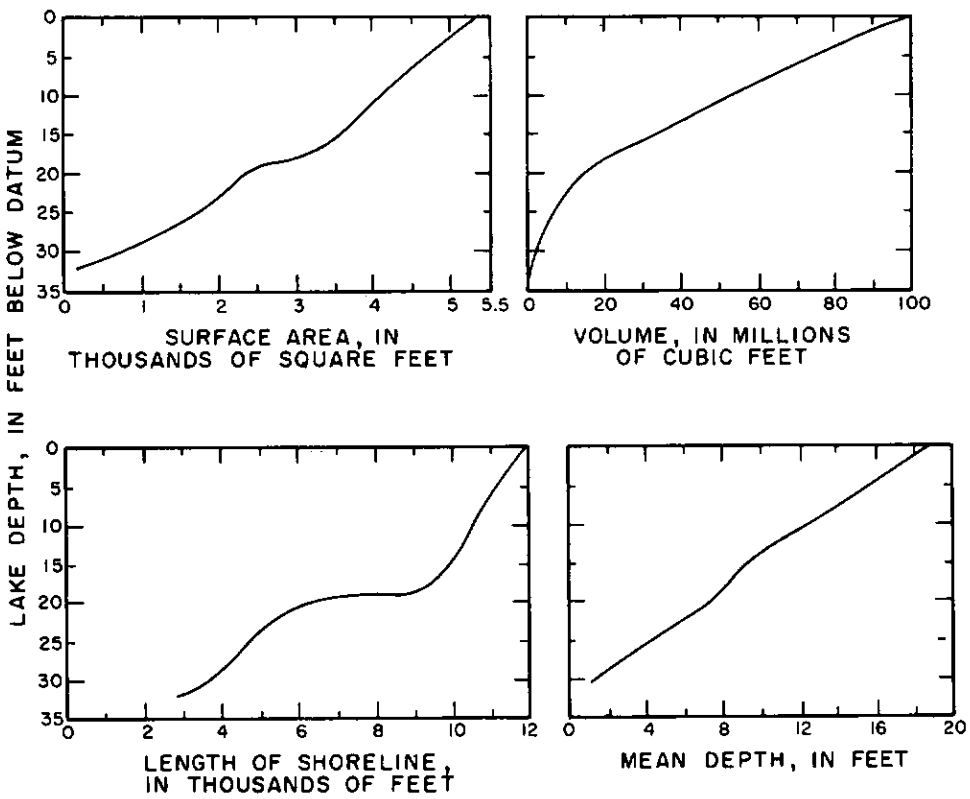


FIGURE 16. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Wildcat Lake near Bremerton. Zero-depth datum is 377 feet above mean sea level, based on topographic-map altitude.

Figure 16 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 17 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

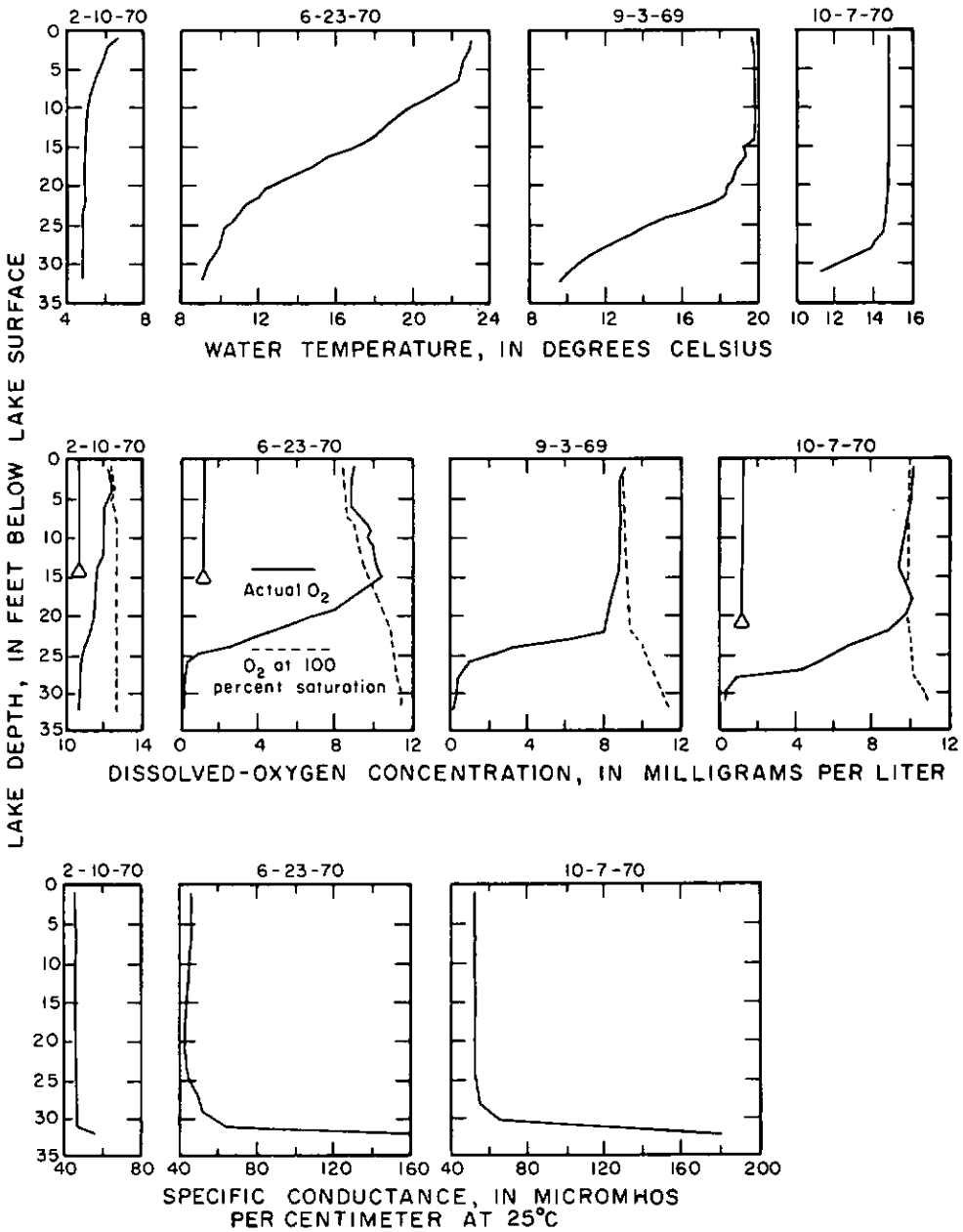


FIGURE 17. – Selected seasonal profiles of lake-water temperature, DO concentration, and specific conductance, Wildcat Lake near Bremerton, 1969-70. Secchi-disc transparency depths are indicated by base of triangles on DO profiles. DO profile for June 23 shows a slight positive heterograde development.

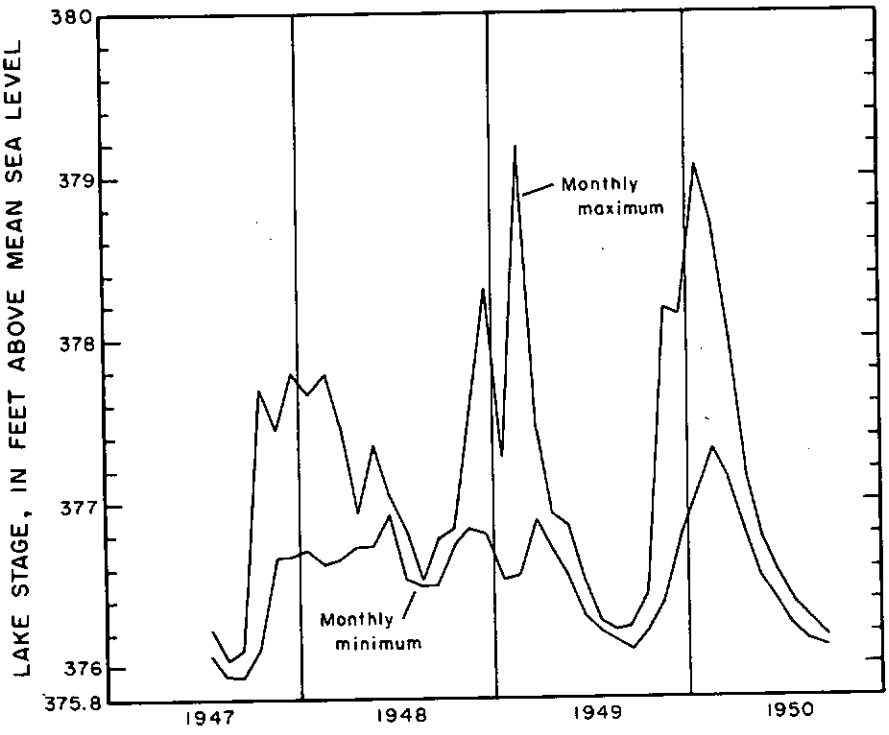


FIGURE 18. -- Observed monthly maximum and monthly minimum lake stages, Wildcat Lake near Bremerton, 1947-50.

Lake stages.--Lake stages observed on Geological Survey staff gage approximately twice weekly from June 1947 to October 1950.

A hydrograph of the monthly maximum and minimum observed lake stages for the period of record is shown in figure 18. Observations of lake-stage altitude during the data-collection period are as follows:

Date	Lake stage (in ft above msl)
9- 3-69	375.67
2-10-70	376.23
6-23-70	375.81
10- 7-70	375.74
10-26-70	376.07

Surface-water inflow and outflow.--Surface-water outflow via Wildcat Creek.

The outflow is through a well-developed channel on the northeast side of the lake. Some sources of surface-water inflow are precipitation, local storm runoff, and from

several intermittent streams draining hills south and west of the lake.

Flows measured at three inflow sites and at the lake outlet are as follows:

Date	Inflow (in cfs)	Outflow (in cfs)
9- 3-69	0	0
2-10-70	2.17	6.99
6-23-70	.24	.38
10- 7-70	.11	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-10-70	10-7-70	10-7-70
Depth of samples below surface, in ft	16	[a]3 and 15	29
Silica (SiO_2)	7.2	6.6	7.6
Iron (Fe)	--	--	--
Manganese (Mn)	--	--	--
Calcium (Ca)	4.3	4.8	5.8
Magnesium (Mg)	1.5	2.0	2.0
Sodium (Na)	1.7	2.3	2.1
Potassium (K)	.3	.1	.2
Bicarbonate (HCO_3)	21	28	32
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	.4	1.9	1.6
Chloride (Cl)	1.7	1.2	1.3
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	39	44	51
Hardness Ca-Mg	17	20	23
Hardness Noncarbonate	0	0	0
Alkalinity	17	23	26
pH, units	6.8	7.0	6.7
Color, Co-Pt units	5	5	10

[a] Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 17.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 3-69	1	0.000	0.010	0.00	--	--	--	0.20
2-10-70	16	.006	.013	.10	--	--	--	.30
6-23-70	30	.003	.020	.04	--	--	--	.20
10- 7-70	3	.013	.036	.04	0.000	0.02	0.11	.13
10- 7-70	15	.010	.013	.02	.000	.02	.09	.11
10- 7-70	29	.036	.036	.20	.000	.24	.01	.45

Macrophytes.--Area of macrophytes 0.3 percent of lake area, October 7, 1970.

The lake contained waterlily (Nuphar and Nymphaea), watershield (Brasenia), several small patches of sedge (Cyperus), and bulrushes (Scirpus).

Conclusions.--Wildcat Lake probably could be considered a lake with medium biologic productivity, based on moderate transparency, an oxygen deficit in the hypolimnion and periods of slight oxygen supersaturation in the metalimnion in the summer dissolved-oxygen profile, and moderate winter nutrient concentrations. The macrophyte population was found to be relatively low.

12071500. Kitsap Lake near Bremerton

Location.--Surface-water outflow (Kitsap Creek) at lat 47°34'47", long 122°42'34".

Ninety percent of the lake is in sec. 17 and 10 percent in sec. 18, T.24 N., R.1 E., Kitsap County.

Origin.--Kettle lake formed in preglacial drainage channel.

Basin geology.--Glacial recessional outwash deposits with till hills in northern portion of the basin and volcanic rocks in south and southwest.

Soils.--Gravelly and sandy loam soils, with imperfectly drained silt to the south, on flat to steep slopes.

Land use and cover.--Approximately one-half the lake basin is dense suburban development and other half is forest with a few residences.

Vegetation in the developed area consists of lawns, deciduous trees, and some conifers. The forested area is mainly second-growth fir and cedar with an undergrowth of salal and huckleberry.

Population.--House count of October 1970 noted more than 90 dwellings on the lakeshore, as compared to about 55 lakeshore residences in 1953 (estimated from U.S. Geological Survey topographic map).

Northern, northwestern, and eastern shores of the lake have the greatest home density. South and southwest shoreline of the lake is low and marshy, making it less desirable for homesites.

Physical features of lake.--Bathymetric map shown in figure 19 (Wolcott, 1965, p. 212).

Some morphometric parameters, at a lake stage of 156 ft (msl), are:

Drainage area-------- 2.73 sq mi	Length of shoreline- 14,200 ft
Altitude of deepest part of lake (using msl datum)---------- 127 ft	Length of lake------ 5,370 ft
	Breadth of lake----- 2,560 ft
	Shoreline configuration-- 1.22
Surface area- 10.8 million sq ft	Development of volume---- 0.62
Lake volume---195 million cu ft	Relative depth---- 0.8 percent
Mean depth---------- 18.1 ft	Mean slope---------- 1°47'
Maximum depth---------- 29 ft	

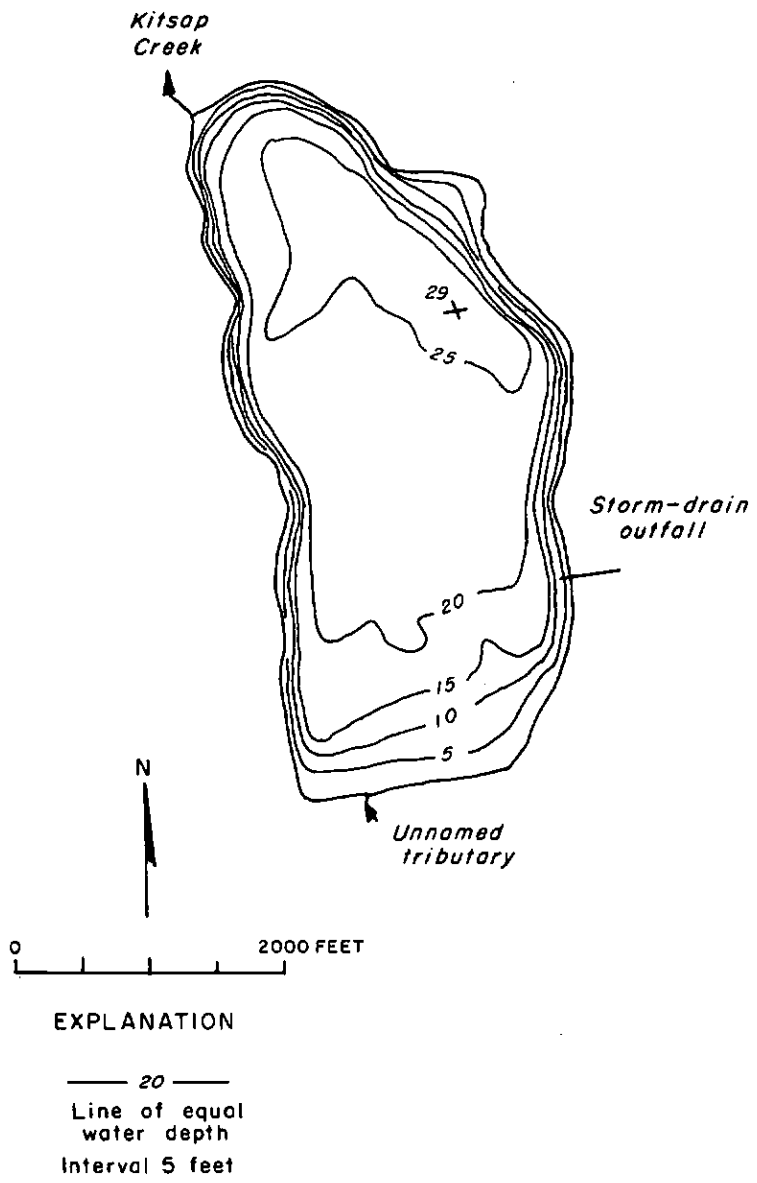


FIGURE 19. – Kitsap Lake near Bremerton, surveyed June 7, 1950 by State Department of Game (map from Wolcott, 1965, p. 212). Zero-depth datum is 156 ft. (msl).

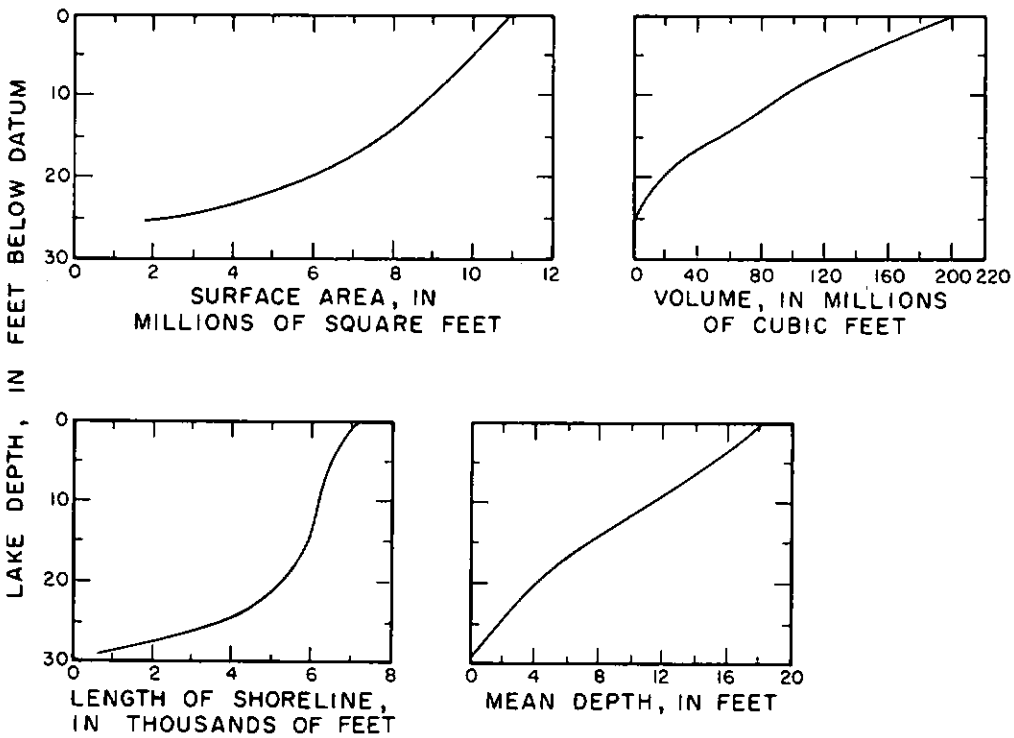


FIGURE 20. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Kitsap Lake near Bremerton. Zero-depth datum is 156 feet above mean sea level, based on topographic-map altitude.

Figure 20 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 21 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

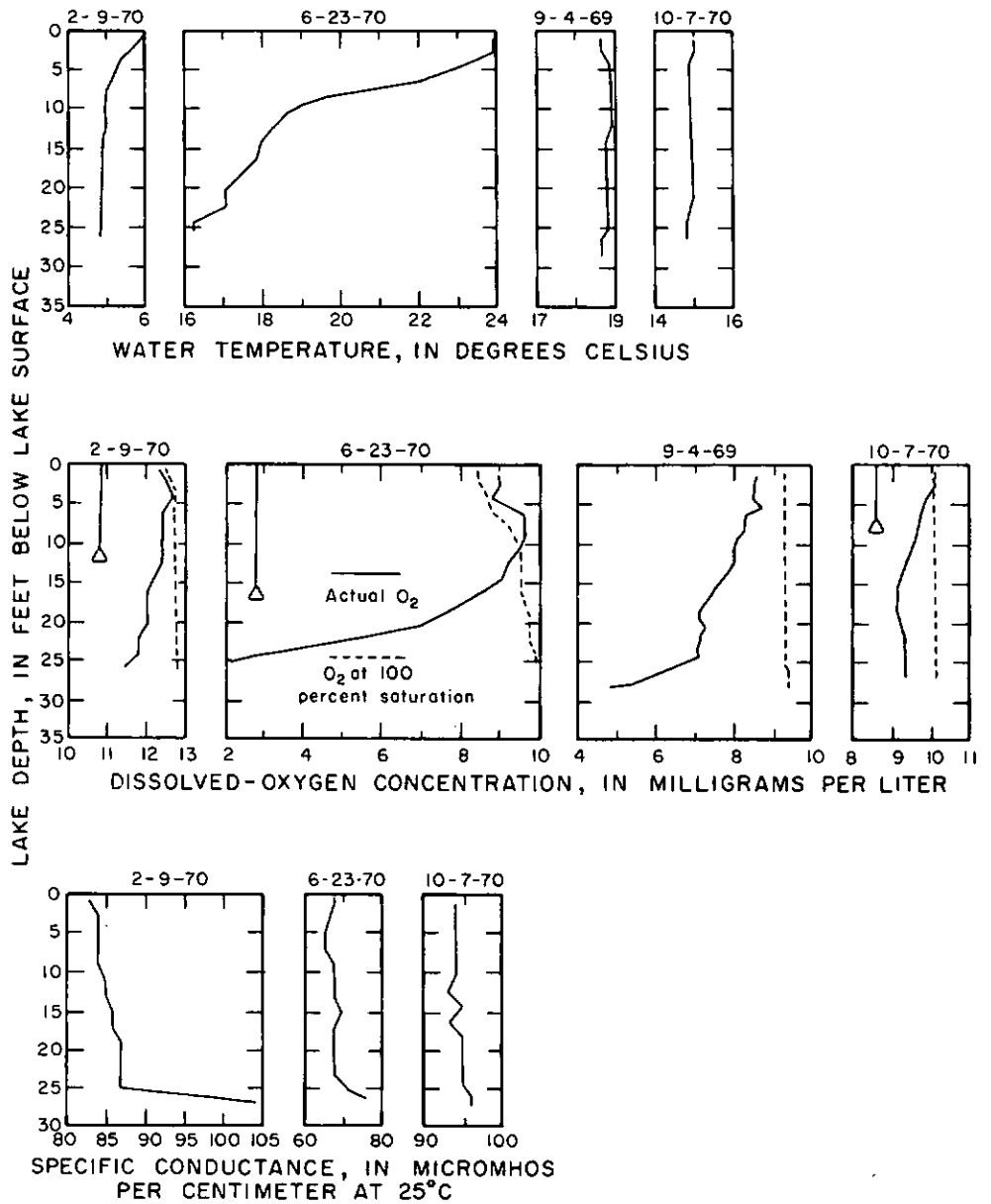


FIGURE 21. – Selected seasonal profiles of lake-water temperature, DO concentration, and specific conductance, Kitsap Lake near Bremerton, 1969-70. Secchi-disc transparency depths are indicated by the base of the triangles on DO profiles. DO profile for June 23 shows a slight positive heterograde development.

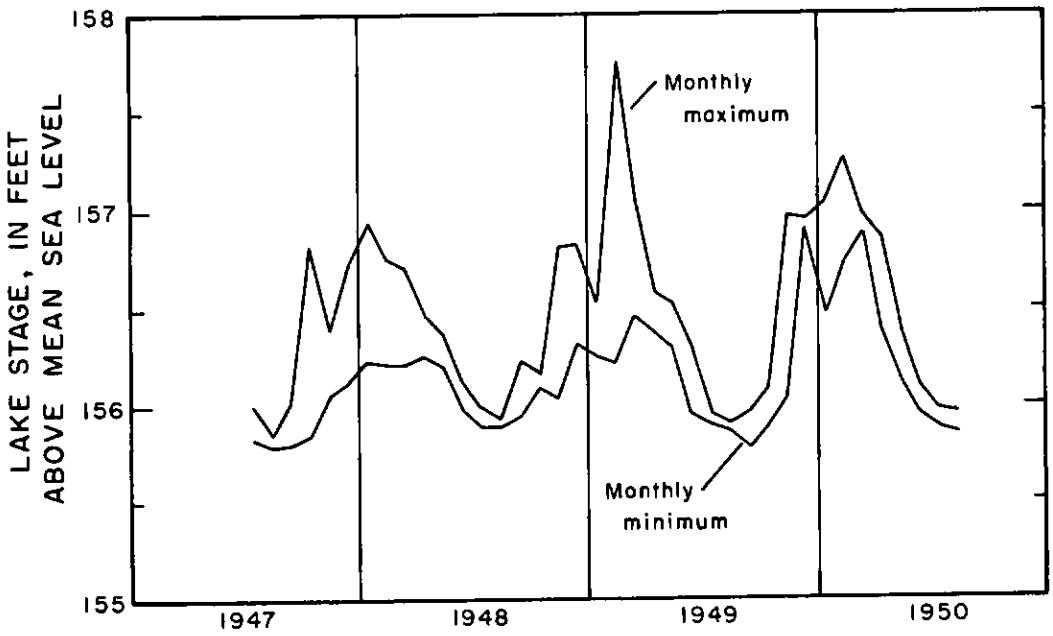


FIGURE 22. – Monthly maximum and monthly minimum lake stages, Kitsap Lake near Bremerton, 1947-50.

Lake stages.--Hydrograph of monthly maximum and minimum lake stages from July 1947 to September 1950 shown in figure 22.

From a staff gage (datum 156 ft msl) the following observations of lake stage were made:

Date	Lake stage (in ft above msl)
9- 4-69	156.44
2- 9-70	156.87
6-23-70	155.96
10- 7-70	155.95
10-26-70	156.46

Surface-water inflow and outflow.--Inflow enters southern part of lake from a stream with a poorly developed channel.

Additional inflow comes from precipitation, storm runoff (there is a storm-drain outfall on the east side of the lake), and a fair amount of ground water from the southern part of the basin. Outflow, via Kitsap Creek, is from the north end of the lake, through a narrow gap between two hills composed of till.

Below are listed miscellaneous flow measurements (only outflow measurements were made until Sept. 4, 1969).

Date	Outflow (in cfs)	Date	Inflow (in cfs)	Outflow (in cfs)
7- 8-47	1.35	5-25-49	--	4.46
7-23-47	.69	6-29-49	--	1.28
8- 5-47	.43	8- 4-49	--	.59
8-27-47	.40	9-14-49	--	.34
9-17-47	2.00	10-22-49	--	1.87
9-30-47	1.45	11-29-49	--	25.2
12-11-47	3.15	1-19-50	--	11.9
1-14-48	17.0	2-24-50	--	21.3
2-19-48	20.1	4- 4-50	--	13.4
3-29-48	13.7	5-16-50	--	5.16
5- 7-48	11.3	6-27-50	--	2.51
6-17-48	4.16	8- 8-50	--	.95
7-16-48	2.23	8-13-50	--	.36
8-20-48	1.45	8-21-50	--	.08
9-29-48	6.50	8-25-50	--	.48
11-17-48	13.2	9- 4-69	1.04	.56
1- 5-49	12.0	2-10-70	4.62	12.1
2-14-49	10.3	6-23-70	1.34	1.89
3-17-49	10.9	10- 7-70	1.16	2.14
4-21-49	6.45			

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-9-70	10-7-70
Depth of samples below surface, in ft	13	[a] 3,15, and 25
Silica (SiO_2)	16	18
Iron (Fe)	--	--
Manganese (Mn)	--	--
Calcium (Ca)	8.6	9.8
Magnesium (Mg)	3.3	3.8
Sodium (Na)	3.3	3.7
Potassium (K)	.4	.4
Bicarbonate (HCO_3)	42	54
Carbonate (CO_3)	0	0
Sulfate (SO_4)	3.0	1.6
Chloride (Cl)	2.8	2.5
Fluoride (F)	.1	.1
Dissolved solids (residue at 180°C)	64	78
Hardness Ca-Mg	35	40
Hardness Noncarbonate	1	0
Alkalinity	34	44
pH, units	7.2	7.2
Color, Co-Pt units	5	5

[a] Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 21.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 4-69	1	0.003	0.016	0.00	--	--	--	0.10
2- 9-70	13	.003	.016	.14	--	--	--	.40
6-23-70	22	.000	.003	.07	--	--	--	.20
10- 7-70	3	.026	.026	.00	0.000	0.09	0.01	.10
10- 7-70	15	.026	.026	.00	.009	.06	.02	.09
10- 7-70	25	.023	.023	.00	.009	.05	.02	.08

Macrophytes.--Area of macrophytes 2.0 percent of lake area, October 7, 1970.

The dominant aquatic plants found in the lake were waterlily (Nuphar and Nymphaea), bulrush (Scirpus), and cattail (Typha). The waterlily growth (mainly Nuphar) was greatest in the shallow southern end of the lake where patches existed 300 to 500 ft from shore.

Remarks.--On September 11, 1969 and October 7, 1970 algal blooms were observed.

Conclusions.--A slight oxygen supersaturation in the matalimnion during the summer stratification period, a specific conductance slightly higher than that of many of the other lakes in this vicinity, and aquatic flora and fauna observations indicate Kitsap Lake has a medium to high biologic productivity. However, because of a moderate rate of flushing it is not as biologically productive as would be expected when the sources of cultural enrichment surrounding the lake are considered.

12072675. Crescent Lake near Gig Harbor

Location.--Surface-water outflow (Crescent Creek) at south end of lake at lat 47°23'18", long 122°34'18"; lake in SW¼ sec. 16, SE¼ sec. 17, and NE¼ sec. 20, T.22 N., R.2 E., Pierce County.

Origin.--Kettle lake in glacial outwash channel at head of a valley.

Basin geology.--Glacial till and recessional outwash.

Soils.--Gravelly sandy loam soils on moderate slopes.

Land use and cover.--Rural homes, forest, and recreation.

The basin is equally covered by conifer and deciduous trees. The prominent conifers are second-growth cedar, fir, and hemlock, the most abundant deciduous trees are alder, dogwood, madrona, and maple, with willows on the west shore of the lake. The underbrush is salal, swordfern, huckleberry, salmonberry, and blackberry.

Population.--House count of October 1970 noted 33 homes on the lakeshore, as compared to five homes in 1953 and about 15 in 1968 (estimated from U.S. Geological Survey topographic maps). Most of the buildings are from 50 to 100 ft from the edge of the water, while several are at the edge of the water.

Physical features of lake.--Littoral zone of lake is generally muck, silt and sand, with some gravel.

Bathymetric map shown in figure 23 (Wolcott, 1965, p. 332).

Some morphometric parameters, at a lake stage of 166 ft (msl), are:

Drainage area---------- 1.18 sq mi	Length of shoreline-- 7,300 ft
Altitude of deepest part of lake (using msl datum)---------- 137 ft	Length of lake------- 3,280 ft
	Breadth of lake-------- 900 ft
Surface area-- 2.16 million sq ft	Shoreline configuration-- 1.40
Lake volume--- 34.2 million cu ft	Development of volume---- 0.54
Mean depth---------- 15.8 ft	Relative depth---- 1.3 percent
Maximum depth---------- 29 ft	Mean slope---------- 3°43'

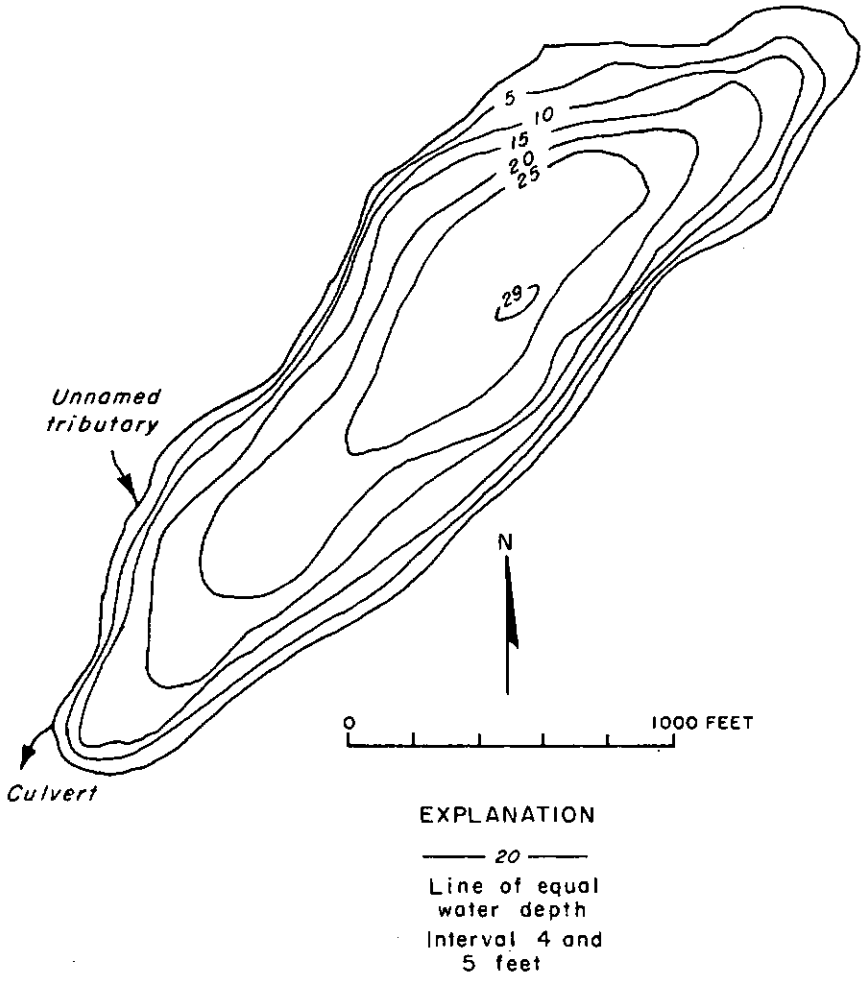


FIGURE 23. – Crescent Lake near Gig Harbor, surveyed August 19, 1947 by State Department of Game (map from Wolcott, 1965, p. 332). Zero-depth datum is 166 ft. (msl).

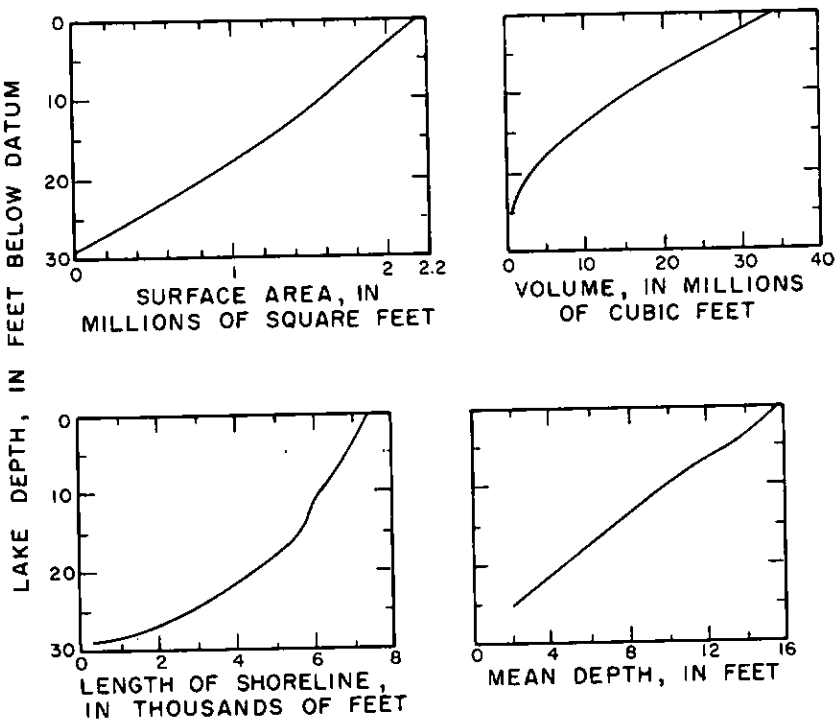


FIGURE 24. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Crescent Lake near Gig Harbor. Zero-depth datum is 166 feet above mean sea level, based on topographic-map altitude.

Figure 24 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 25 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9- 2-69	165.72
2-11-70	167.65
6-19-70	166.23
10- 5-70	166.62

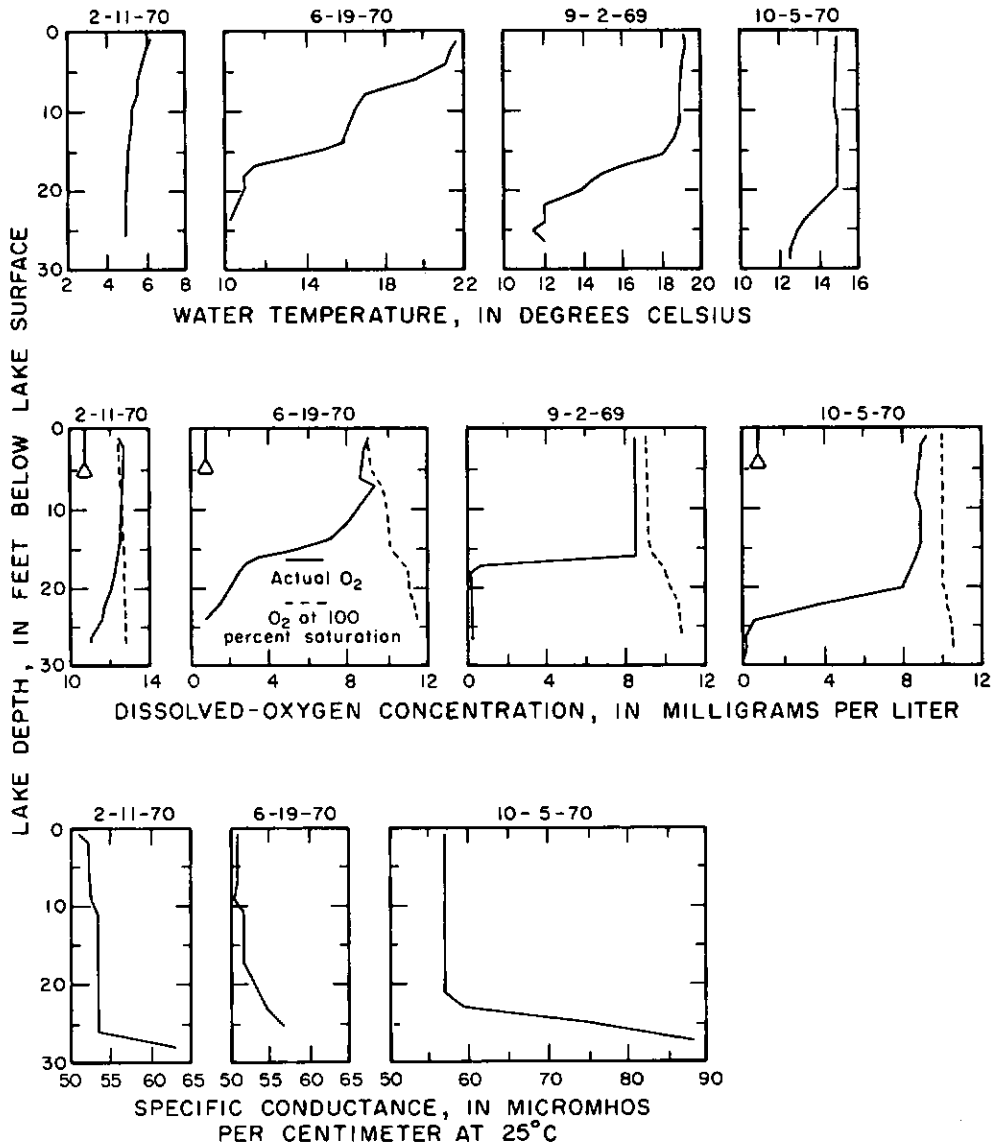


FIGURE 25. – Selected seasonal profiles of lake-water temperature, DO concentration, and specific conductance, Crescent Lake near Gig Harbor, 1969-70. Secchi-disc transparency depths are indicated by base of triangles on DO profiles.

Surface-water inflow and outflow.--Outlet is through a culvert which is usually partly clogged.

Some inflow is from a small channel on the southwest side of the lake. Miscellaneous measurements of inflow and outflow are listed below:

Date	Inflow (in cfs)	Outflow (in cfs)
9- 2-69	0.1	dry
2-11-70	.64	3.75
6-19-70	dry	.40
10- 5-70	.1	.29

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-11-70	10-5-70
Depth of samples below surface, in ft	14	[a] 4,15, and 25
Silica (SiO_2)	6.9	6.7
Iron (Fe)	--	--
Manganese (Mn)	--	--
Calcium (Ca)	4.1	4.1
Magnesium (Mg)	2.1	2.3
Sodium (Na)	2.7	3.1
Potassium (K)	.5	.4
Bicarbonate (HCO_3)	17	24
Carbonate (CO_3)	0	0
Sulfate (SO_4)	4	3.4
Chloride (Cl)	3.3	2.7
Fluoride (F)	.1	.1
Dissolved solids (residue at 180°C)	48	57
Hardness Ca-Mg	19	18
Hardness Noncarbonate	5	0
Alkalinity	14	20
pH, units	6.8	6.9
Color, Co-Pt units	50	30

[a]Averages for three samples; constituents did not vary significantly, despite the stratification shown in figure 25.

Graphs of specific conductance versus depth are shown in figure 25.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 2-69	1	0.000	0.020	0.01	--	--	--	0.30
2-11-70	14	.006	.013	.50	--	--	--	.60
6-19-70	21	.003	.190	.20	--	--	--	.70
10- 5-70	4	.010	.013	.02	0.000	0.07	0.21	.28
10- 5-70	15	.010	.010	.07	.000	.06	.22	.38
10- 5-70	25	.013	.026	.04	.000	.16	.12	.28

Macrophytes.--Area of macrophytes 4 percent of lake area, October 5, 1970.

The dominant aquatic plants found in the lake were watershield (Brasenia), waterlily (Nuphar and Nymphaea), sedge (Cyperus), and bulrush (Scirpus). Some local attempts at aquatic plant eradication were observed on the northeast end of the lake, otherwise plants were found to be nearly continuous around the lake.

Remarks.--Dirt fills are being made on the southwest shore, between the lake's inlet and the outlet, and also on the southeast shore.

Conclusions.--In 2 years (1968-70) the number of lakeshore dwellings around Crescent Lake has doubled. The natural eutrophication rate is probably quite high because of the lake's low altitude and the swamp-type environment around parts of the lake, which results in a fairly high lake color. The abundance of macrophytes, the moderately high winter nutrient content, the shallow transparency depth, the summer oxygen deficit in the hypolimnion, and the increasing sources of nourishment add up to a lake of moderately high biologic productivity.

12073585. Jackson Lake near Home

Location.--Southernmost tip of lake at lat 47°17'10", long 122°46'19"; lake in SW¼ sec. 23 and NW¼ sec. 26, T.21 N., R.1 W., Pierce County.

Origin.--Kettle lake.

Basin geology.--Glacial till and outwash deposits.

Soils.--Gravelly sandy loam soils on moderate slopes.

Land use and cover.--Mainly recreation and some pasture.

Vegetal cover on the basin is conifers and deciduous trees in approximately equal numbers. The conifers are second-growth fir and cedar and deciduous trees are alder and madrona; Underbrush is mainly huckleberry and salal. There is about 8 acres of grassland northwest of lake.

Population.--House count of October 1970 noted 27 dwellings on the lakeshore, as compared to only one dwelling on the lakeshore in 1953 and about 10 in 1968 (estimated from U.S. Geological Survey topographic maps). Only seven of present dwellings appeared to be full-time residences; the remainder were summer-use cabins.

Physical features of lake.--Littoral zone of lake composed of muck and silt with some sand and interspersed cobble and gravel.

Bathymetric map shown in figure 26 (Wolcott, 1965, p. 297).

Some morphometric parameters, at a lake stage of 196 ft (msl), are:

Drainage area	0.32 sq mi	Length of shoreline	3,540 ft
Altitude of deepest part of lake (using msl datum)	166 ft	Length of lake	1,450 ft
Surface area	742,000 sq ft	Breadth of lake	680 ft
Lake volume	11.4 million cu ft	Shoreline configuration	1.16
Mean depth	15.4 ft	Development of volume	0.51
Maximum depth	30 ft	Relative depth	3.1 percent
		Mean slope	5°28'

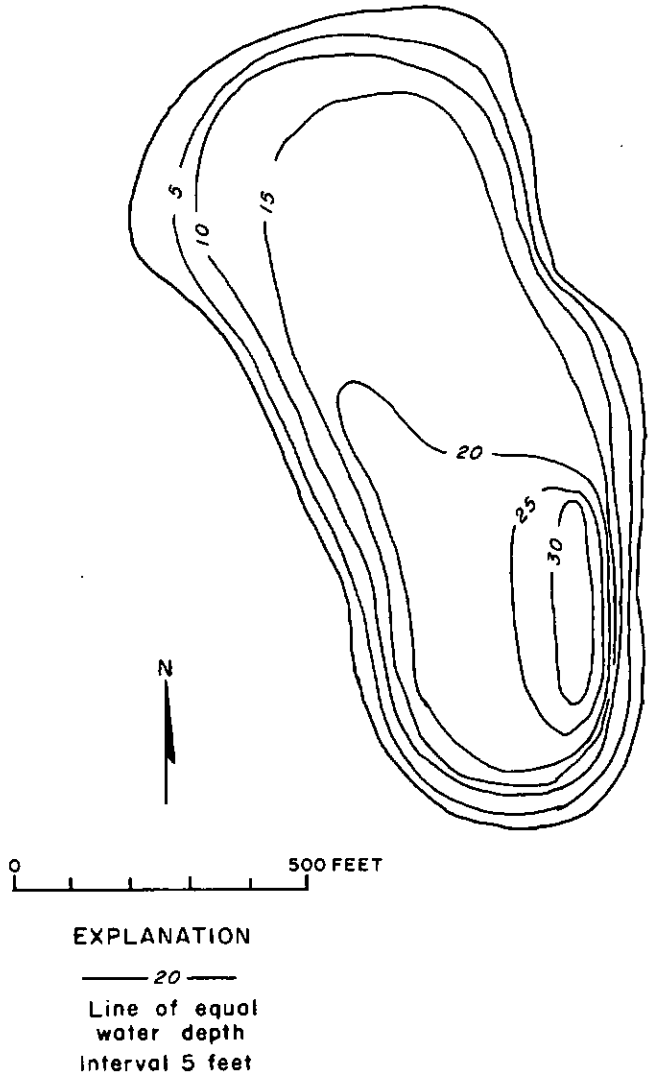


FIGURE 26. – Jackson Lake near Home, surveyed August 16, 1954 by State Department of Game (map from Wolcott, 1965, p. 297). Zero-depth datum is 196 ft. (msl).

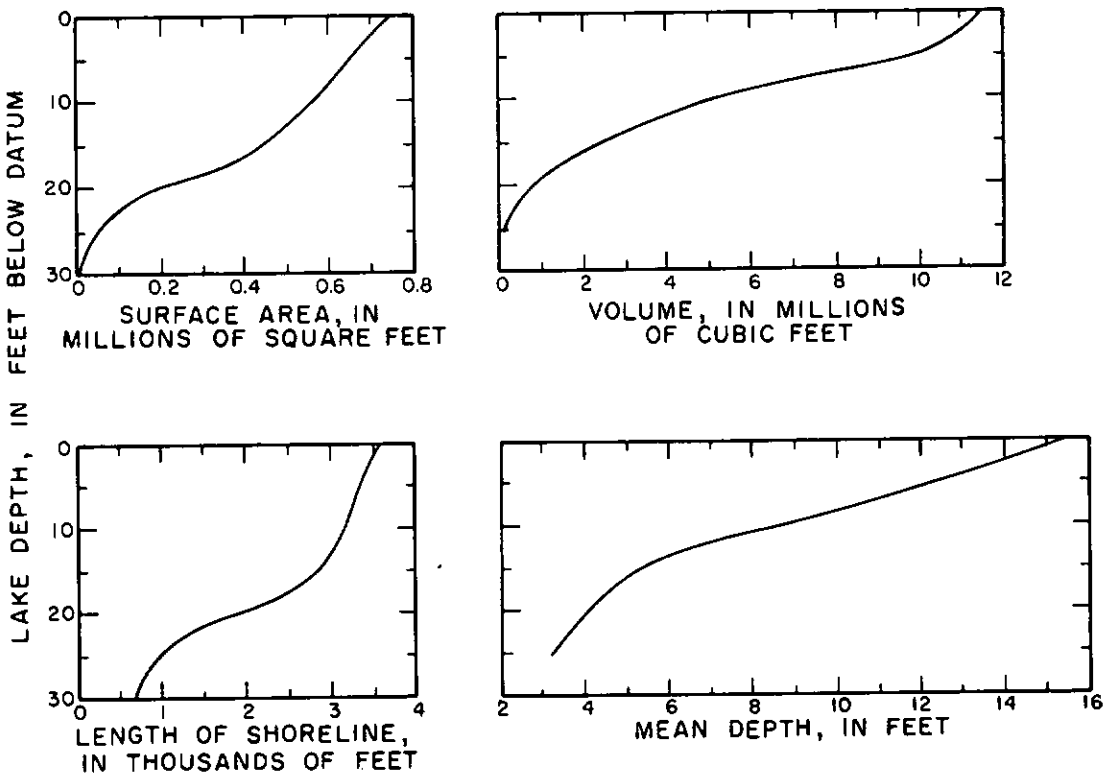


FIGURE 27. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Jackson Lake near Home. Zero-depth datum is 196 feet above mean sea level, based on topographic-map altitude.

Figure 27 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 28 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-11-69	195.92
2-11-70	198.79
6-30-70	197.19
10-5-70	195.54

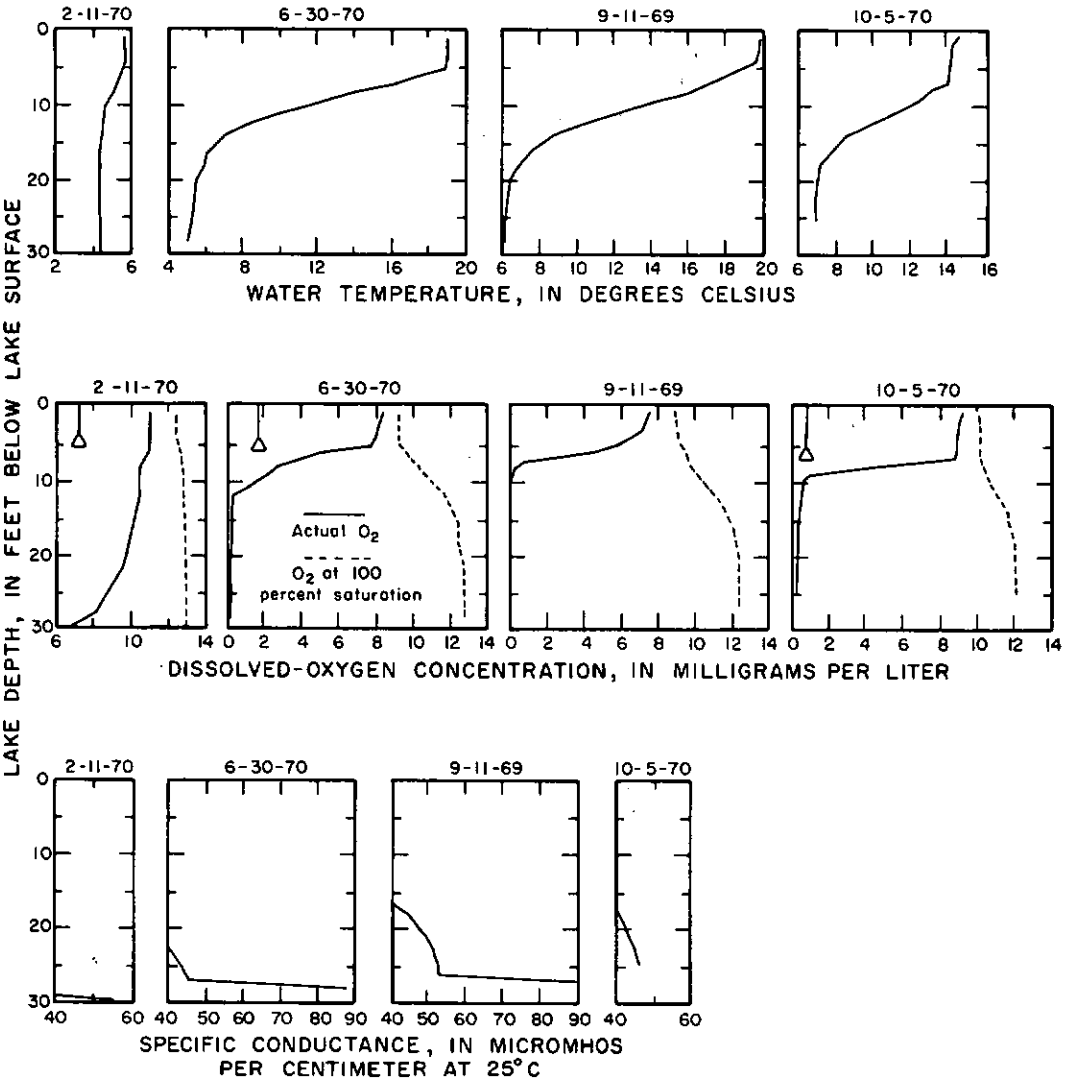


FIGURE 28. — Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Jackson Lake near Home, 1969-70. Secchi-disc transparency depths are indicated by the base of the triangles on DO profiles. Conductance data below 40 μmhos/cm were not collected.

Surface-water inflow and outflow.--No visible surface-water inflow or outflow channels.

The lake receives water from ground water, precipitation, and local storm runoff and loses water through ground water and evapotranspiration.

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-11-70	10-5-70	10-5-70
Depth of samples below surface, in ft	15	[a] 4 and 8	23
Silica (SiO_2)	4.4	1.7	7.2
Iron (Fe)	--	--	--
Manganese (Mn)	--	--	--
Calcium (Ca)	2.0	1.8	2.4
Magnesium (Mg)	1.1	1.1	1.1
Sodium (Na)	1.8	2.0	1.9
Potassium (K)	.4	.2	.4
Bicarbonate (HCO_3)	11	12	14
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	.2	1.0	.8
Chloride (Cl)	2.5	2.2	2.3
Fluoride (F)	.1	.1	.2
Dissolved solids (residue at 180°C)	32	32	44
Hardness Ca-Mg	10	9	11
Hardness Noncarbonate	1	0	0
Alkalinity	9	10	11
pH, units	6.4	6.4	6.4
Color, Co-Pt units	40	40	60
Specific conductance, µmhos/cm	29	31	36

[a] Averages for two samples; constituents did not vary significantly, despite the stratification shown in figure 28.

Graphs of specific conductance versus depth are shown in figure 28.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-11-69	1	0.003	0.016	0.09	--	--	--	0.80
2-11-70	15	.006	.023	.10	--	--	--	.30
6-30-70	24	.085	.088	.20	--	--	--	.30
10- 5-70	4	.006	.020	.20	0.000	0.55	0.02	.77
10- 5-70	8	.059	.072	.10	.000	.11	.12	.33
10- 5-70	23	.180	.190	.09	.000	.48	.01	.59

Macophytes.--Area of macrophytes 16 percent of lake area, October 5, 1970.

The dominant aquatic plants found in the lake were watershield (Brasenia), waterlily (Nuphar and Nymphaea), cattail (Typha), and sedge (Cyperus). The plant growth was quite evenly distributed around the entire shore of the lake.

Conclusions.--The number of dwellings around Jackson Lake has almost tripled in 2 years (1969-70). The lake is comparatively small and has the least volume of lake water per dwelling of all the lakes in this report. The lake has a moderately high color (probably from the natural environment), has no surface-water inflow or outflow, has good potential for enrichment, and favors biologic productivity--as evidenced by the abundance of macrophytes, the summer oxygen deficit in the hypolimnion, and the low transparency of the water. Because of the shape (development of volume is 0.51) and color of the lake, oxygen may be deficient in the lower part of the profile even during maximum winter mixing.

12087300. Clear Lake near Eatonville

Location.--Surface-water outflow at lat 46°55'48", long 122°15'40"; lake in secs. 26 and 27, T.17 N., R.4 E., Pierce County.

Origin.--Well-formed kettle lake.

Basin geology.--Glacial-outwash and till deposits laid upon earlier till deposits and, in the vicinity of and west of the lake, deposits of clay, sand, and lignite.

Soils.--Moderately deep gravelly sandy loam soils with nearly level to moderately steep slopes.

Land use and cover.--Mainly residential and recreational.

The majority of the basin is covered with second-growth fir and deciduous trees.

Population.--House count of October 1970 noted 122 dwellings on or near lakeshore, as compared to 105 dwellings in 1959 and 110 in 1968 (estimated from U.S. Geological Survey topographic maps). Twenty percent of the present dwellings are summer residences.

Physical features of lake.--Bathymetric map shown in figure 29 (Wolcott, 1965, p. 308).

Some morphometric parameters, at a lake stage of 772 ft (msl), are:

Drainage area	0.41 sq mi	Length of shoreline	11,000 ft
Altitude of deepest part of lake (using msl datum)	687 ft	Length of lake	4,060 ft
Surface area	7.05 million sq ft	Breadth of lake	2,590 ft
Lake volume	267 million cu ft	Shoreline configuration	1.17
Mean depth	37.8 ft	Development of volume	0.45
Maximum depth	85 ft	Relative depth	2.8 percent
		Mean slope	4°08'

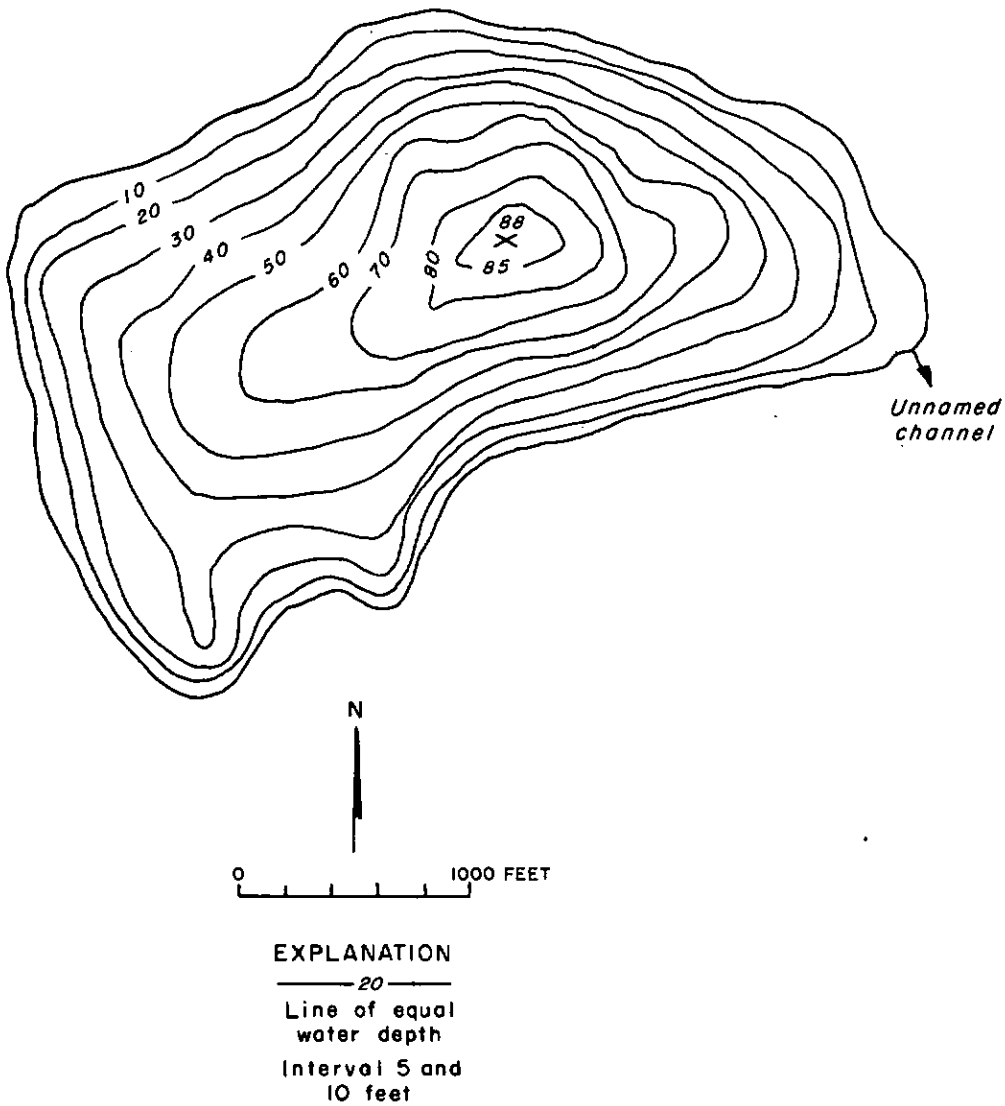


FIGURE 29. – Clear Lake near Eatonville, surveyed February 7, 1949 by State Department of Game (map from Wolcott, 1965, p. 308). Zero-depth datum is 772 ft. (msl).

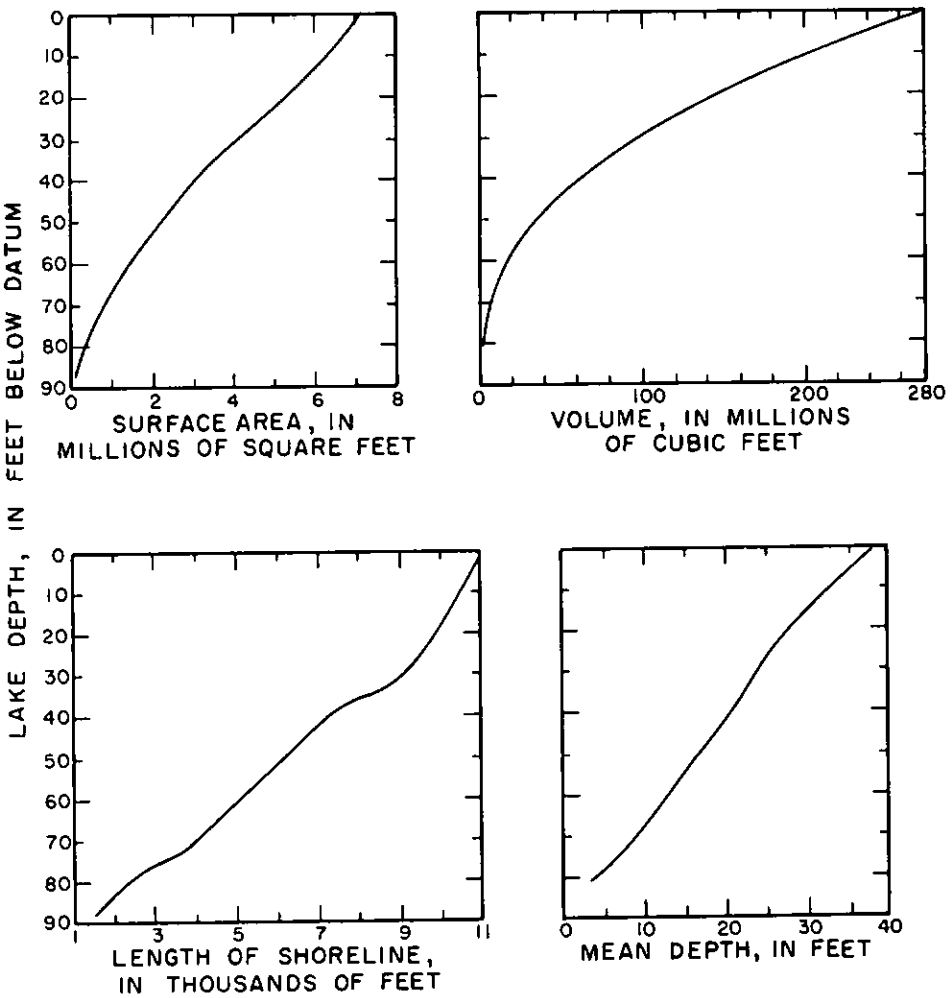


FIGURE 30. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Clear Lake near Eatonville. Zero-depth datum is 772 feet above mean sea level, based on topographic-map altitude.

Figure 30 shows relations of area, volume, length of shoreline, and mean depth to stage; figures 31, 32, and 33 show profiles of water temperature, DO concentration, and specific conductance, as well as Secchi-disc transparency depths.

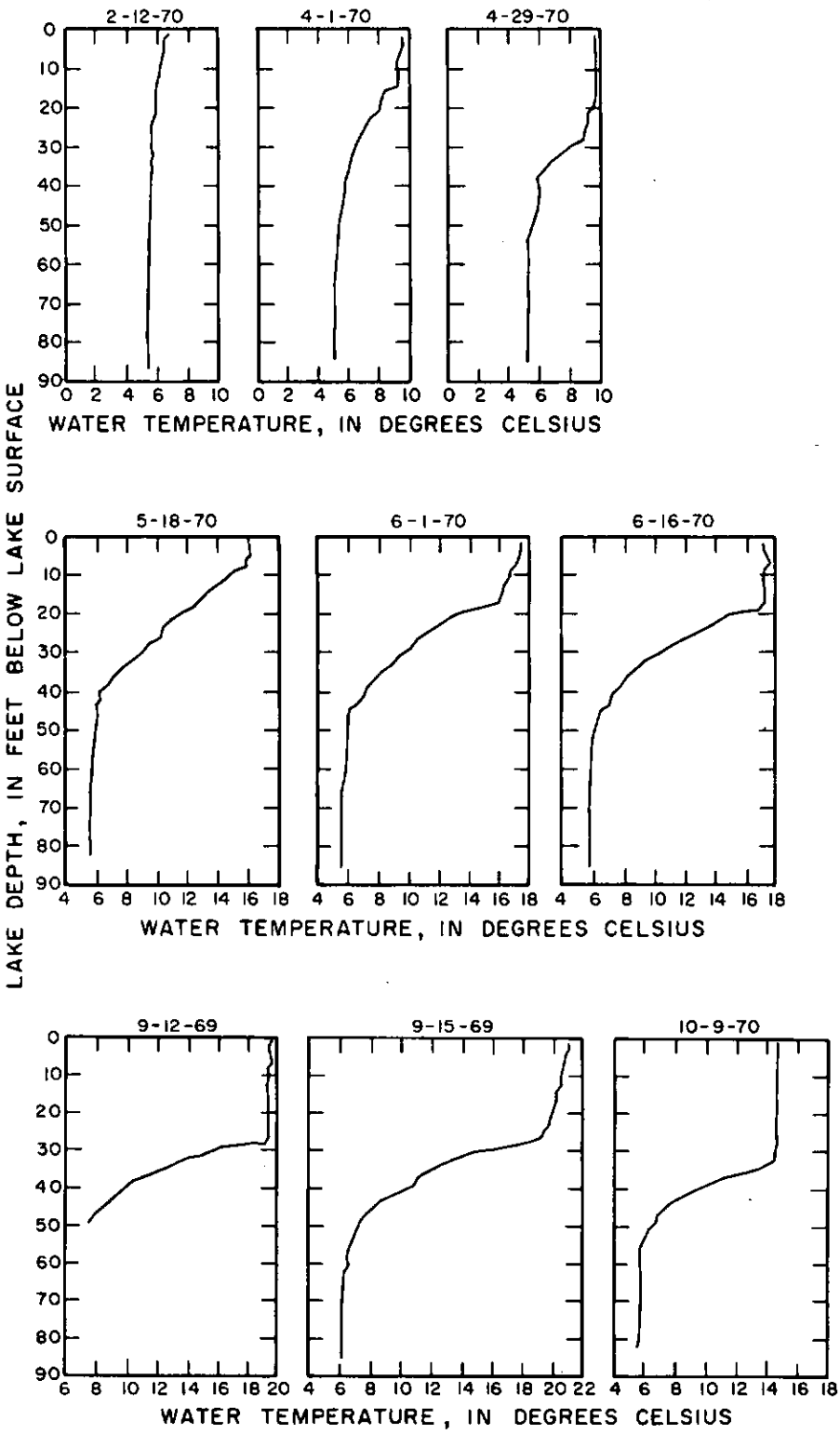


FIGURE 31. – Selected seasonal profiles of water temperature, Clear Lake near Eatonville, 1969-70.

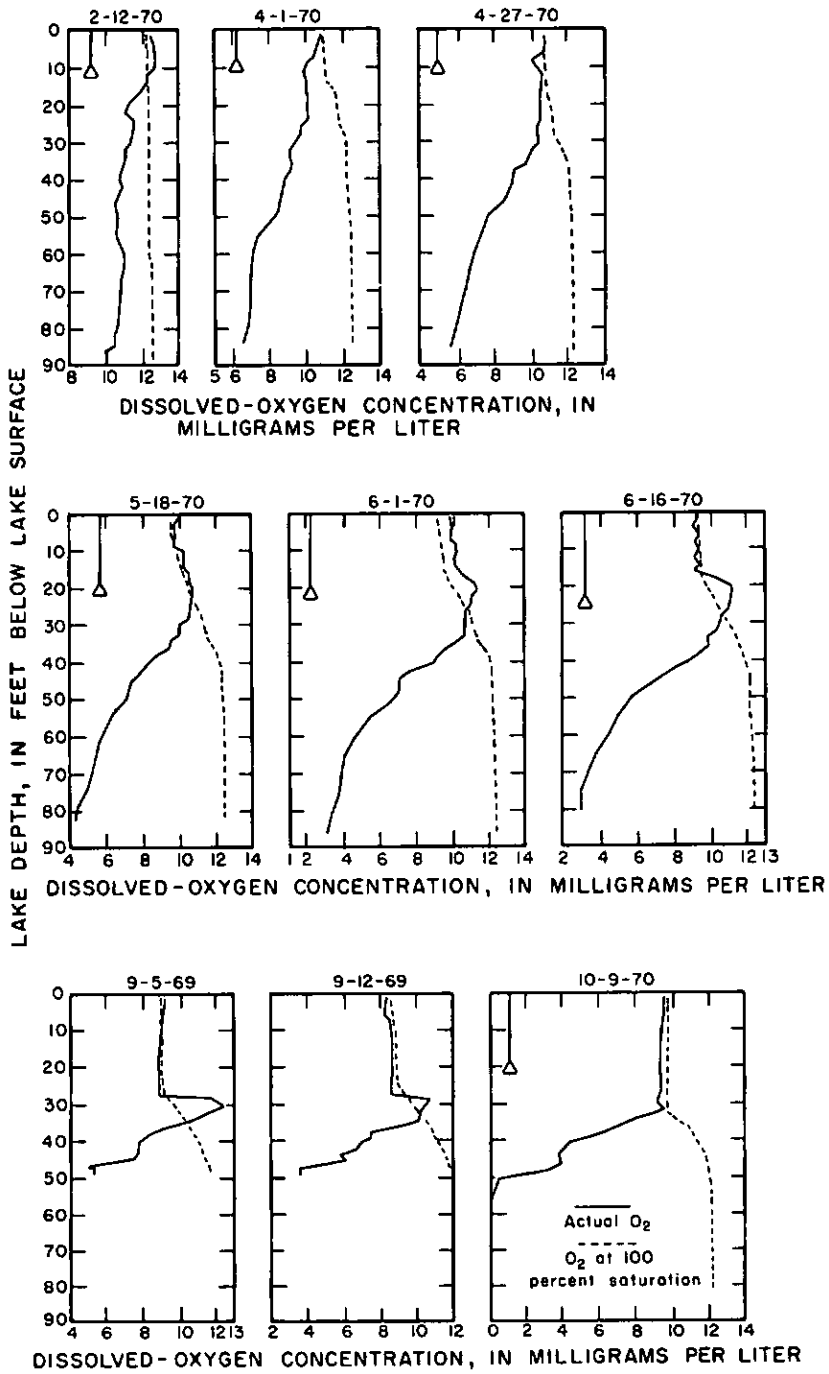


FIGURE 32. – Selected seasonal profiles of DO concentration, Clear Lake near Eatonville, 1969-70. DO profiles for June 1 and 16 and September 5 and 12 show positive heterograde development. Secchi-disc transparency depths are shown by base of the triangles on the DO profiles. Note the positive heterograde development for DO profiles for June 16 and September 5, 12. Profile for June 16 shows 118-percent oxygen saturation and profile for September 5 shows 123-percent oxygen saturation at depths of 20 and 25 ft., respectively.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9- 5-69	771.80
9-12-69	771.74
2-12-70	772.80
4- 1-70	772.48
4-29-70	772.60
5-18-70	772.50
6- 1-70	772.43
6-16-70	772.31
10- 9-70	771.49

Surface-water inflow and outflow.--No visible surface-water inflow into lake.

The lake receives inflow from ground water, precipitation, and local storm runoff. Surface-water outflow is intermittent and occurs through a channel on the east end of the lake. Miscellaneous measurements of outflow are listed below.

Date	Outflow (in cfs)
9- 5-69	0
9-12-69	0
2-12-70	2.02
4- 1-70	.3
4-29-70	.8
5-18-70	.7
6- 1-70	0
6-16-70	.01
10- 9-70	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated			
Date of sampling	2-12-70	10-9-70	10-9-70	10-9-70
Depth of samples below surface, in ft	40	3	40	72
Silica (SiO_2)	1.4	1.1	1.6	3.2
Iron (Fe)	--	.03	.04	2.5
Manganese (Mn)	--	.01	.03	.20
Calcium (Ca)	3.9	3.5	3.5	4.0
Magnesium (Mg)	1.5	1.4	1.3	1.5
Sodium (Na)	3.1	3.2	3.2	3.2
Potassium (K)	.9	.8	.8	.8
Bicarbonate (HCO_3)	21	20	22	24
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	3.4	5.0	4.8	5.5
Chloride (Cl)	3.0	2.3	2.4	2.3
Fluoride (F)	.0	.0	.0	.1
Dissolved solids (residue at 180°C)	28	34	36	37
Hardness Ca-Mg	16	15	14	16
Hardness Noncarbonate	0	0	0	0
Alkalinity	17	16	18	20
pH, units	6.9	7.1	6.8	6.5
Color, Co-Pt units	0	0	0	20

Graphs of specific conductance versus depth are shown in figure 33.

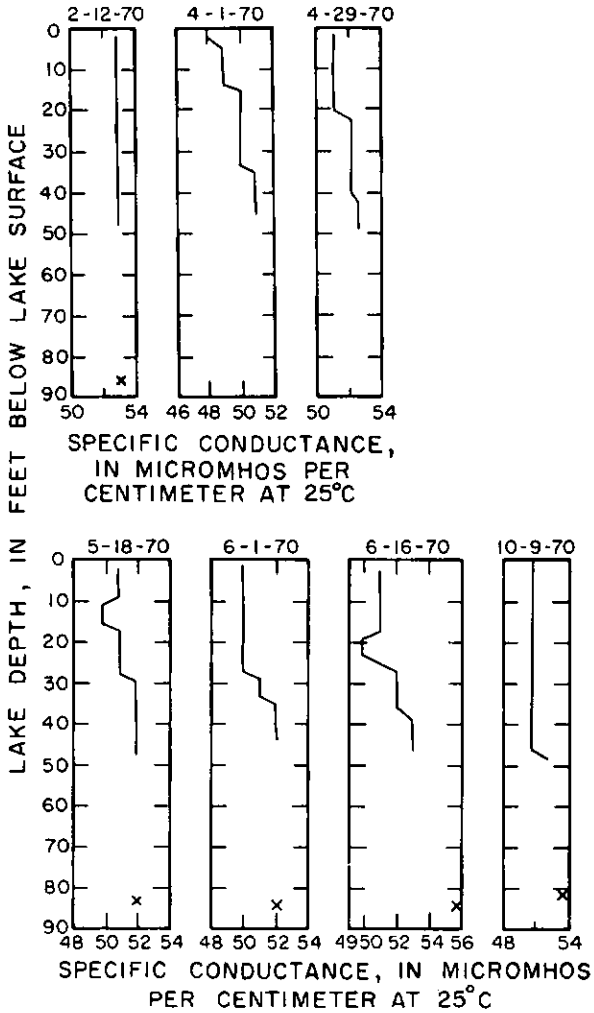


FIGURE 33. – Selected seasonal profiles of specific conductance, Clear Lake near Eatonville, 1969-70. On dates and depths marked by an "x", a point sample of lake water was used for the conductance determinations.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 5-69	1	0.000	0.006	0.00	--	--	--	0.09
2-12-70	40	.003	.020	.02	--	--	--	.20
6-16-70	80	.013	.072	.02	--	--	--	.07
10- 9-70	3	.000	.009	.00	0.000	0.00	0.08	.08
10- 9-70	40	.003	.013	.00	.000	.06	.10	.16
10- 9-70	72	.100	.120	.04	.036	.07	.11	.22

Macrophytes.--Area of macrophytes 1.3 percent of lake area, October 9, 1970.

The dominant aquatic plant found in the lake was milfoil (Myriophyllum). Minor patches of cattail (Typha), watercelery (Vallisneria), and waterlily (Nuphar) were also found.

Remarks.--Considerable seepage from Clear Lake into Ohop Creek basin on the east, evidenced by springs along the west side of Ohop valley.

Several lakeshore residents pump water from the lake.

Conclusions.--Clear Lake for at least the past 10 years has had an abundant source of nutrient enrichment from the large number of lakeshore dwellings. However, the lake has a comparatively large volume, and flushing is accomplished through both surface- and ground-water inflow and outflow. This large volume and rate of flushing, in conjunction with complete mixing during the winter (when the highest flushing rates occur), results in less biologic productivity than would be expected. The medium biologic productivity and the trophic nature of the lake is evidenced mainly by a zone of oxygen supersaturation in the metalimnion--doubtless due to photosynthesis in these stabilized layers--and by some oxygen deficit in the hypolimnion of the summer dissolved-oxygen profiles.

12087400. Ohop Lake near Eatonville

Location.--Surface-water outflow at lat 46°53'06", long 122°16'38"; lake in sec. 35, T.17 N., R.4 E., and secs. 2,3, 10, and 11, T.16 N., R.4 E., Pierce County.

Origin.--The Ohop Creek valley was cut by a large stream carrying melt water from the Pleistocene ice sheet.

Presently the valley is occupied by Ohop Creek, a small underfit stream. The lake was formed in the valley behind a dam composed of the deltaic deposits of Lynch Creek which is an eastern tributary to Ohop Creek.

Basin geology.--Valley floor is covered by alluvium and some peat, with glacial-outwash deposits to east and west.

The upper and eastern part of the basin includes bedrock outcrop.

Soils.--Gravelly loamy sand with some clay loam and peat deposits, on nearly level to steep slopes.

Land use and cover.--Upland areas forest covered, valleys occupied by small farms.

Near the northeastern end of the basin clay is mined and a brick kiln has been built. The lake itself is used mainly for recreation purposes. Basin vegetal cover consists of pasture grassland and forests of conifer and deciduous trees with an understory of salal, huckleberry, blackberry, and ferns.

Population.--House count of October 1970 noted about 160 homes within 200 ft of the lake's shoreline.

Most of the buildings are situated along the sides of the lake because both the inflow, at the north end, and the outflow, at the south end, flow through low marshy land which is undesirable for building.

Physical features of lake.--Littoral zone marshy at and around inflow and outflow, rest of the lake's littoral zone composed of clay, silt, and sand with interspersed cobble and gravel.

Bathymetric map shown in figure 34 (Wolcott, 1965, p. 304).

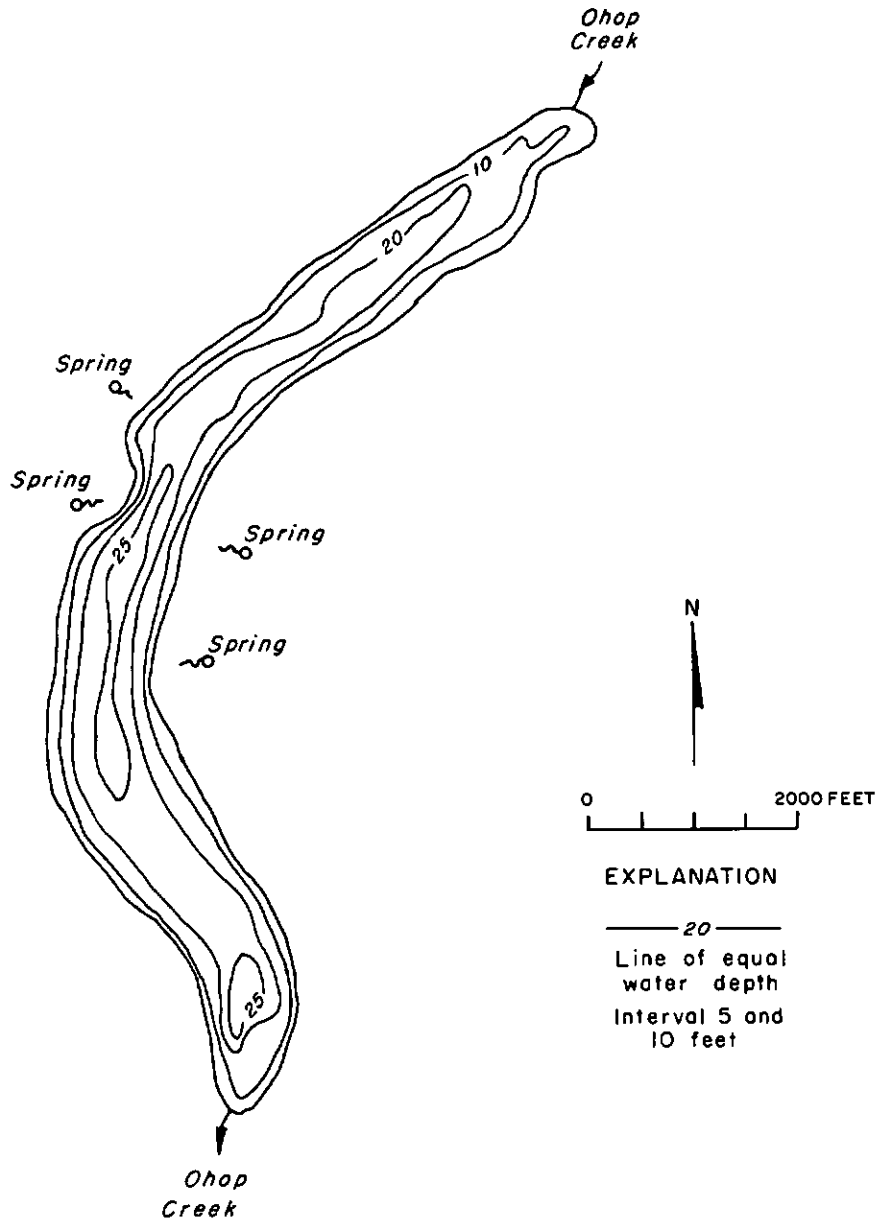


FIGURE 34. – Ohop Lake near Eatonville, surveyed June 14, 1954 by State Department of Game (map from Wolcott, 1965, p. 304). Zero-depth datum is 524 ft. (msl).

Some morphometric parameters, at a lake stage of 524 ft (msl), are:

Drainage area-------- 17.3 sq mi	Length of shoreline-- 24,140 ft
Altitude of deepest part of lake (using msl datum)---------- 499 ft	Length of lake------- 11,900 ft
	Breadth of lake------ 1,210 ft
Surface area- 10.0 million sq ft	Shoreline configuration--- 2.15
Lake volume--- 166 million cu ft	Development of volume----- 0.66
Mean depth---------- 16.6 ft	Relative depth----- 0.7 percent
Maximum depth---------- 25 ft	Mean slope---------- 2°50'

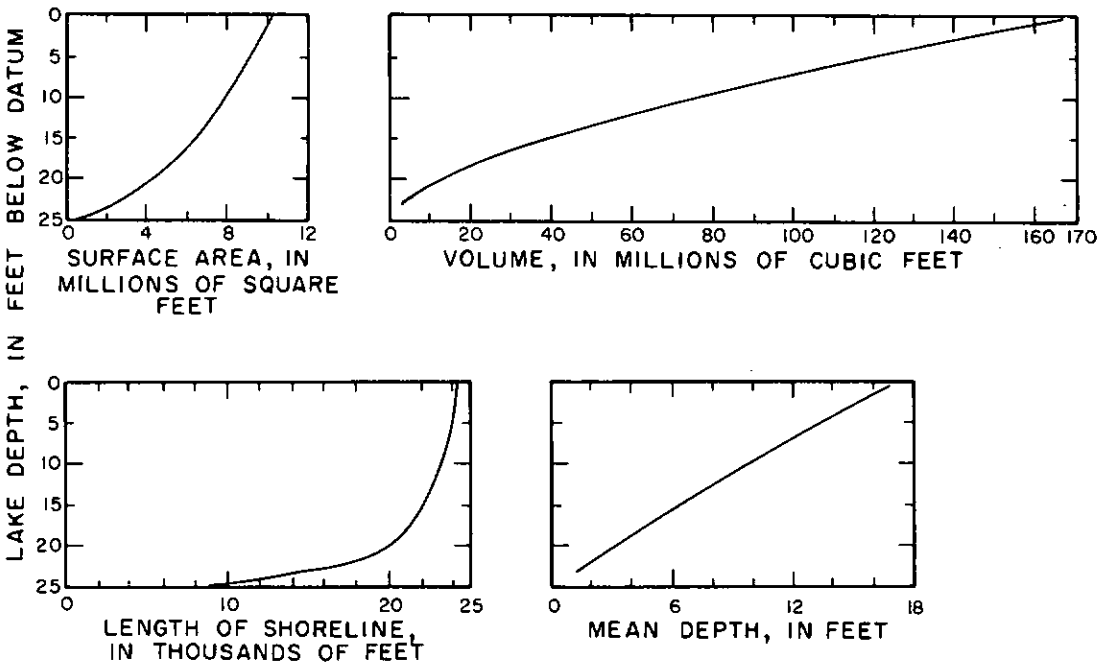
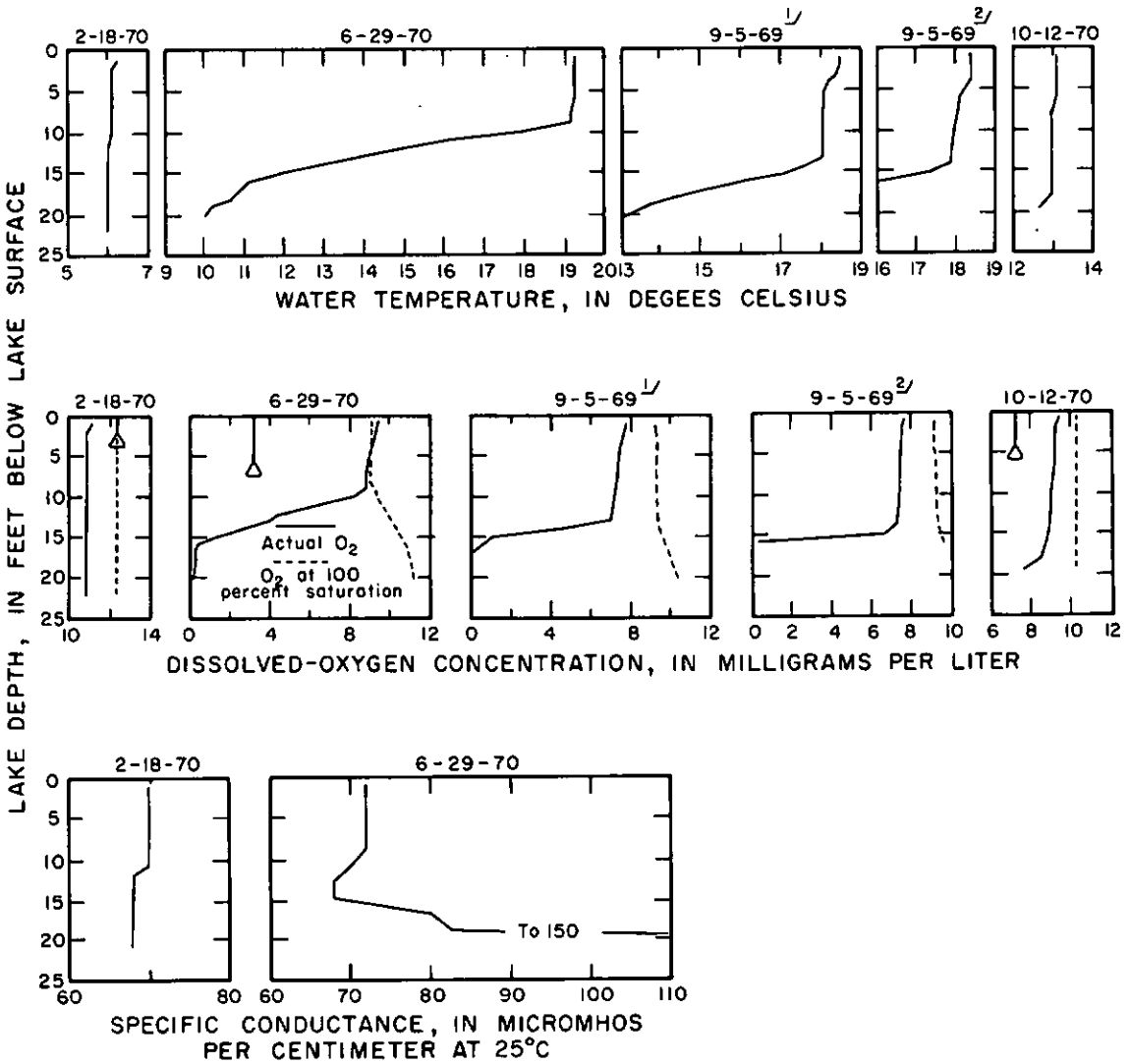


FIGURE 35. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Ohop Lake near Eatonville. Zero-depth datum is 524 feet above mean sea level, based on topographic-map altitude.

Figure 35 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 36 shows profiles of DO concentration, water temperature, and specific conductance, as well as Secchi-disc transparency depths.



1/ Sampled near geographic center in deepest part of lake.

2/ Sampled near south end of lake.

FIGURE 36. – Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Ohop Lake near Eatonville, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. Profiles were measured in deepest part of lake unless otherwise noted.

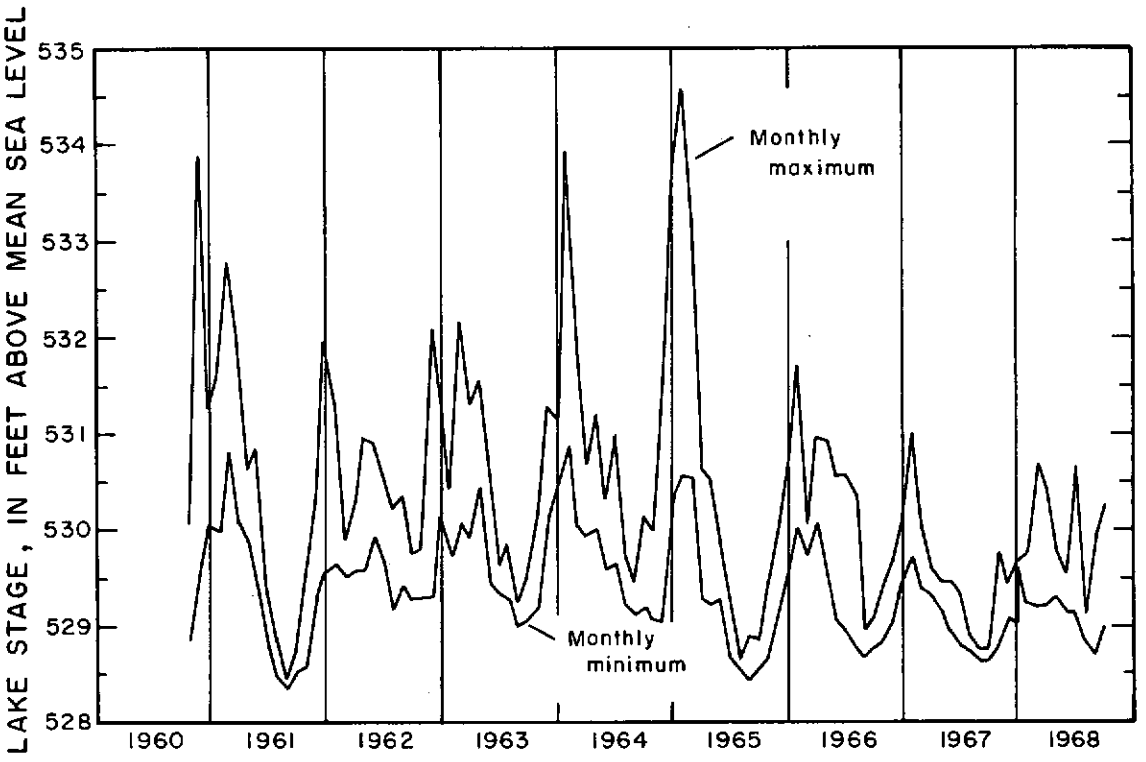


FIGURE 37. – Monthly maximum and monthly minimum lake stages, Ohop Lake near Eatonville, 1960-68.

Lake stages.--Hydrograph of monthly maximum and minimum lake stages during 1960-68 shown in figure 37.

U.S. Geological Survey made once-daily lake-stage observations from August 1960 to September 1968 (12087400. Ohop Lake near Eatonville). Miscellaneous measurements of lake stages during the study (from staff-gage datum of 529 ft msl) are:

Date	Lake stage (in ft above msl)
9- 5-69	528.78
2-18-70	530.23
6-29-70	528.76
10-12-70	528.95

Surface-water inflow and outflow.--Inflow from Ohop Creek and springs on both eastern and western shores.

The U.S. Geological Survey has a gaging station (12088000. Ohop Creek near Eatonville) on the outflow; however,

the flow at this point includes the Lynch Creek tributary, which enters Ohop Creek just below the lake. Miscellaneous measurements of inflow and outflow are listed below (outflow does not include Lynch Creek).

Date	Inflow (in cfs)	Outflow (in cfs)
9- 5-69	1.26	---
2-18-70	69.9	89.2
6-29-70	1.20	1.23
10-12-70	5.0	10.5

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-18-70	10-12-70
Depth of samples below surface, in ft	11	[a]3,10, and 17
Silica (SiO_2)	14	16
Iron (Fe)	--	.19
Manganese (Mn)	--	.03
Calcium (Ca)	5.1	--
Magnesium (Mg)	1.9	--
Sodium (Na)	3.1	--
Potassium (K)	.6	--
Bicarbonate (HCO_3)	18	36
Carbonate (CO_3)	0	0
Sulfate (SO_4)	9.2	7.1
Chloride (Cl)	2.4	2.4
Fluoride (F)	.2	.1
Dissolved solids (residue at 180°C)	57	62
Hardness Ca-Mg	21	--
Hardness Noncarbonate	6	--
Alkalinity	15	30
pH, units	6.6	7.0
Color, Co-Pt units	30	10

[a]Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 36.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9- 5-69	1	0.003	0.013	0.02	--	--	--	0.10
2-18-70	11	.033	.036	.40	--	--	--	.40
6-29-70	18	.003	.020	.07	--	--	--	2.10
10-12-70	3	.003	.006	.20	0.000	0.02	0.02	.24
10-12-70	10	.003	.003	.20	.000	.02	.02	.24
10-12-70	17	.003	.006	.30	.000	.02	.02	.34

Macrophytes.--Area of macrophytes 3 percent of lake area, October 12, 1970.

The dominant aquatic plants were watershield (Brasenia) and waterlily (Nuphar and Nymphaea). Other plants found were milfoil (Myriophyllum), several species of pondweed (Potamogeton), waterweed (Elodea), cattail (Typha), and sedge (Cyperus).

Conclusions.--The flushing rate of Ohop Lake is quite high, especially during the high-precipitation and high-streamflow period of winter. Both the farming and industry in the upper part of the basin and the dwellings around the lake contribute a moderate amount of nutrient enrichment to the lake but, because of the flushing rate, the lake has only moderate biologic productivity. The majority of the macrophytes occur near the inlet and outlet of the lake.

12088300. Silver Lake near LaGrande

Location.--Surface-water outlet at lat 46°52'53", long 122°21'55"; lake in SE¼ sec. 12, T.16 N., R.3 E., Pierce County.

Origin.--Kettle lake.

The lake is part of a southwest-trending kettle chain.

Basin geology.--Recessional moraine of a glacier.

The lithology is mainly till with younger deposits of peat, clay, sand, and lignite.

Soils.--Peat, muck, and gravelly sandy loam on nearly level to moderately sloping bottom lands.

Land use and cover.--Farms on the southeast and northwest sides of the lake, recreation and residential areas on the north and east sides, and only minor development on the south shore.

Away from the lake's edge, the basin is covered by pastureland, second-growth fir and cedar, and deciduous trees. Well-manicured lawns cover about 1,300 ft along the north shore in the residential area.

Population.--House count of 1970 noted 38 structures on north side of lake, most within 200 ft of water's edge, as compared to seven buildings in basin in 1949 (estimated from U.S. Geological Survey topographic map), the closest being about 600 ft from lake.

Physical features of lake.--Bathymetric map shown in figure 38 (Wolcott, 1965, p. 303).

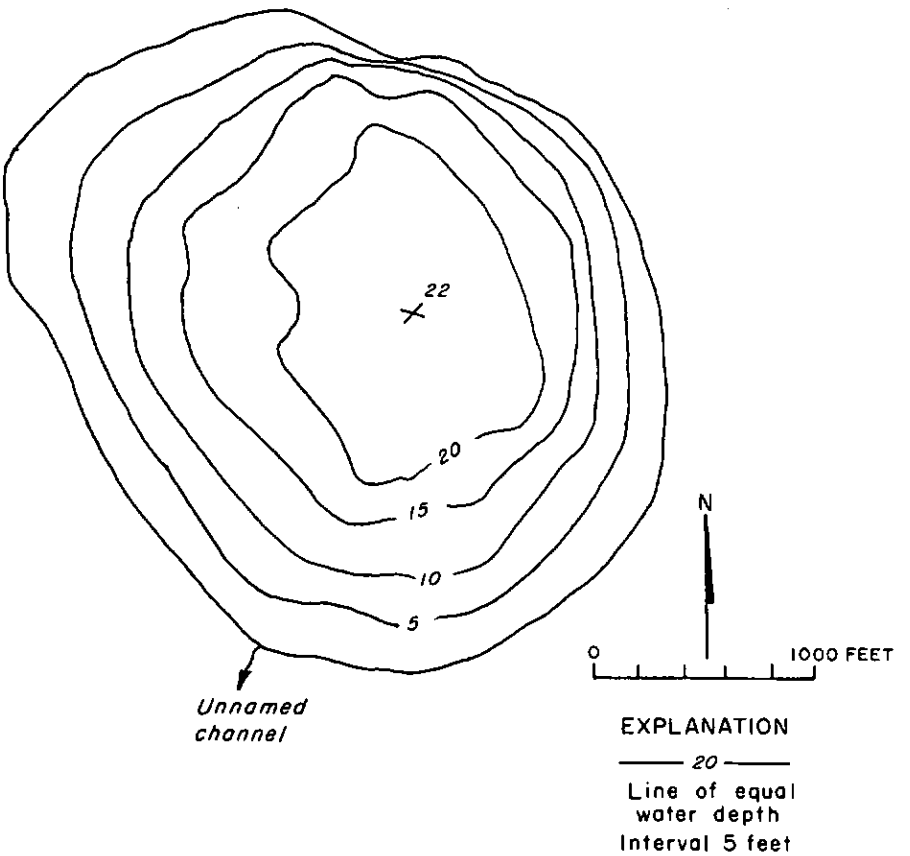


FIGURE 38. – Silver Lake near La Grande, surveyed by State Department of Game (map from Wolcott, 1965, p. 303). Zero-depth datum is 605 ft. (msl).

Some morphometric parameters, at a lake stage of 605 ft (msl), are:

Drainage area	1.83 sq mi	Length of shoreline	9,120 ft
Altitude of deepest part of lake (using msl datum)	583 ft	Length of lake	3,220 ft
		Breadth of lake	2,670 ft
Surface area	6.49 million sq ft	Shoreline configuration	1.01
Lake volume	77.8 million cu ft	Development of volume	0.54
Mean depth	12.0 ft	Relative depth	0.8 percent
Maximum depth	22 ft	Mean slope	1°10'

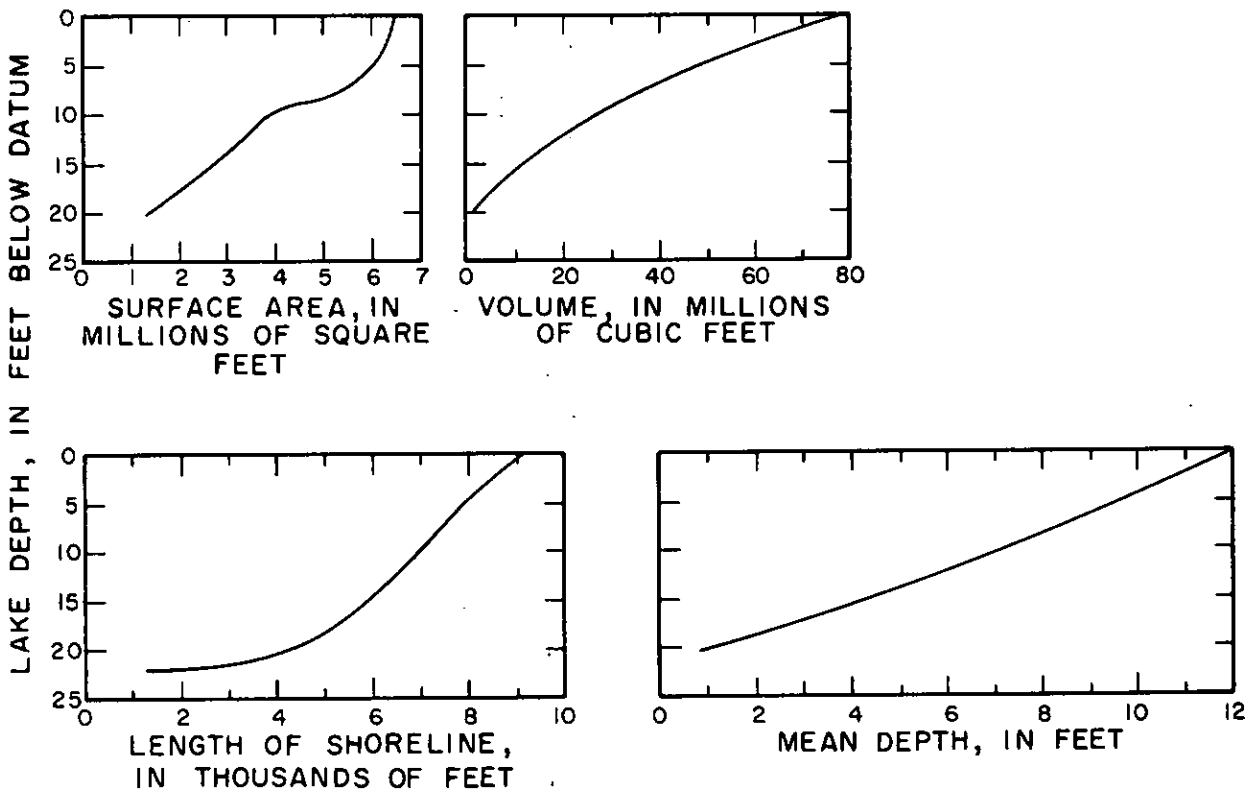


FIGURE 39. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Silver Lake near La Grande. Zero-depth datum is 605 feet above mean sea level, based on topographic-map altitude.

Figure 39 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 40 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-10-69	616.87
2-17-70	617.89
11-10-70	615.64

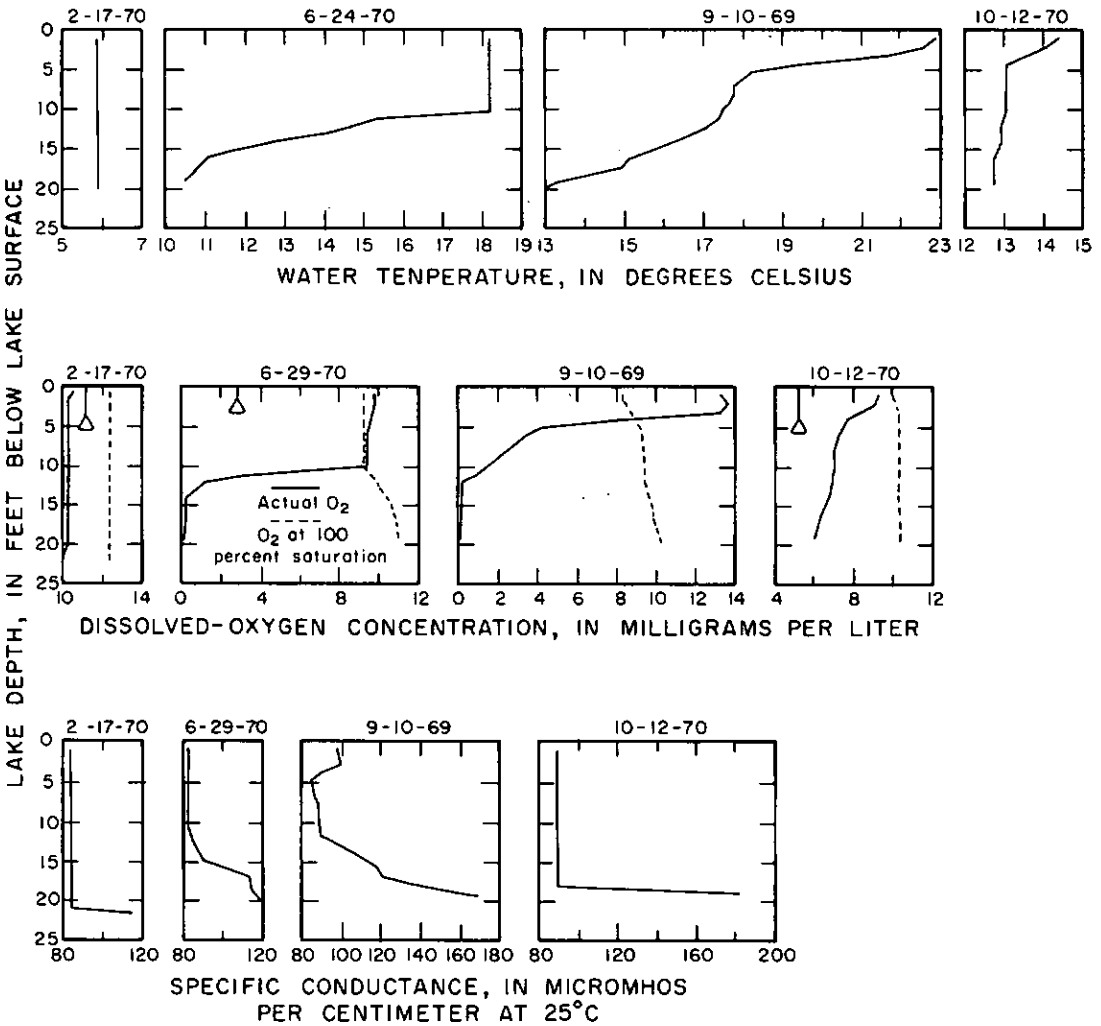


FIGURE 40. – Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Silver Lake near La Grande, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles.

Surface-water inflow and outflow.--No visible surface-water inflow to the lake.

Inflow comes from precipitation, ground-water seepage, and local storm runoff. Outflow on the south side of the lake, is through a moderately well-developed channel. Miscellaneous measurements of outflow are listed below.

Date	Outflow (in cfs)
9-10-69	0
2-17-70	3.20
6-29-70	0
10-12-70	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-17-70	10-12-70
Depth of samples below surface, in ft	11	[a] 3, 10, and 17
Silica (SiO_2)	12	5.6
Iron (Fe)	--	.50
Manganese (Mn)	--	.11
Calcium (Ca)	6.6	--
Magnesium (Mg)	2.8	--
Sodium (Na)	4.1	--
Potassium (K)	1.2	--
Bicarbonate (HCO_3)	34	44
Carbonate (CO_3)	0	0
Sulfate (SO_4)	.8	2.3
Chloride (Cl)	4.2	4.2
Fluoride (F)	.2	.1
Dissolved solids (residue at 180°C)	70	94
Hardness Ca-Mg	28	--
Hardness Noncarbonate	0	--
Alkalinity	28	36
pH, units	6.6	6.9
Color, Co-Pt units	60	20

[a] Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 40.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-10-69	1	0.010	0.052	0.07	--	--	--	1.00
2-17-70	11	.003	.013	.30	--	--	--	.40
6-29-70	18	.390	.390	.30	--	--	--	2.10
10-12-70	3	.033	.049	.50	0.003	0.08	0.03	.61
10-12-70	10	.016	.026	.10	.000	.07	.03	.20
10-12-70	17	.013	.016	.30	.000	.05	.02	.37

Macrophytes.--Area of macrophytes 2.3 percent of lake area, October 12, 1970.

The typical sequence of plants, going from the shallows to the water's edge and on to the land, consists of waterlily (Nuphar and Nymphaea), cattails (Typha), bulrushes (Scirpus), willows and other riparian vegetation. Other aquatic plants found were waterweed (Elodea) and areas of mosses extending into the water.

Remarks.--Algal blooms observed in lake during October 12, 1970 sampling.

Conclusions.--The effects of the high biologic productivity of Silver Lake are reflected in the high specific conductance, the relatively high winter nutrient content, the abundance and distribution of macrophytes, the low transparency depth, the high color and, possibly, the summer oxygen supersaturation

in the near-surface stable layers and the oxygen deficit in the hypolimnion. The near-surface oxygen maxima could be due to physical causes, but observed phytoplankton and the stability of this layer--as evidenced by the thermocline location in the profile--suggest that supersaturation is the result of photosynthesis. The surrounding environment of the lake (farms and some dwellings) are sources of the lake's enrichment, and coupled with a shallow mean depth results in the high biologic productivity and trophic nature of the lake.

12088900. Tanwax Lake near Kapowsin

Location.--Surface-water outlet at lat 46°56'40", long 122°16'26"; lake in secs. 14 and 23, T.17 N., R.4 E., Pierce County.

Origin.--Kettle lake.

The lake is part of a southwest-trending kettle chain formed along preglacial drainage lines.

Basin geology.--Glacial outwash and till deposits with some peat north of the lake.

Soils.--Silt, loam, and gravelly sandy loam on nearly level to moderately sloping bottom lands.

Land use and cover.--Mainly residential with a few acres of pasture.

Approximately 70 percent of the basin's vegetal cover is deciduous trees and 30 percent is conifers, predominantly cedar.

Population.--October 1970 house count in basin noted 47 permanent and 25 seasonal residences, as compared to about 60 total dwellings in 1959 and about 70 in 1968 (estimated from U.S. Geological Survey topographic maps). Presently, permanent structures and trailer houses occupy two-thirds of shoreline.

Physical features of lake.--Bathymetric map shown in figure 41 (Wolcott, 1965, p. 307).

Some morphometric parameters, at a lake stage of 600 ft (msl), are:

Drainage area	4.08 sq mi	Length of shoreline	14,600 ft
Altitude of deepest part of lake (using msl datum)	570 ft	Length of lake	6,060 ft
		Breadth of lake	1,660 ft
Surface area	7.41 million sq ft	Shoreline configuration	1.51
Lake volume	146 million cu ft	Development of volume	0.65
Mean depth	19.7 ft	Relative depth	0.94 percent
Maximum depth	30.0 ft	Mean slope	2°54'

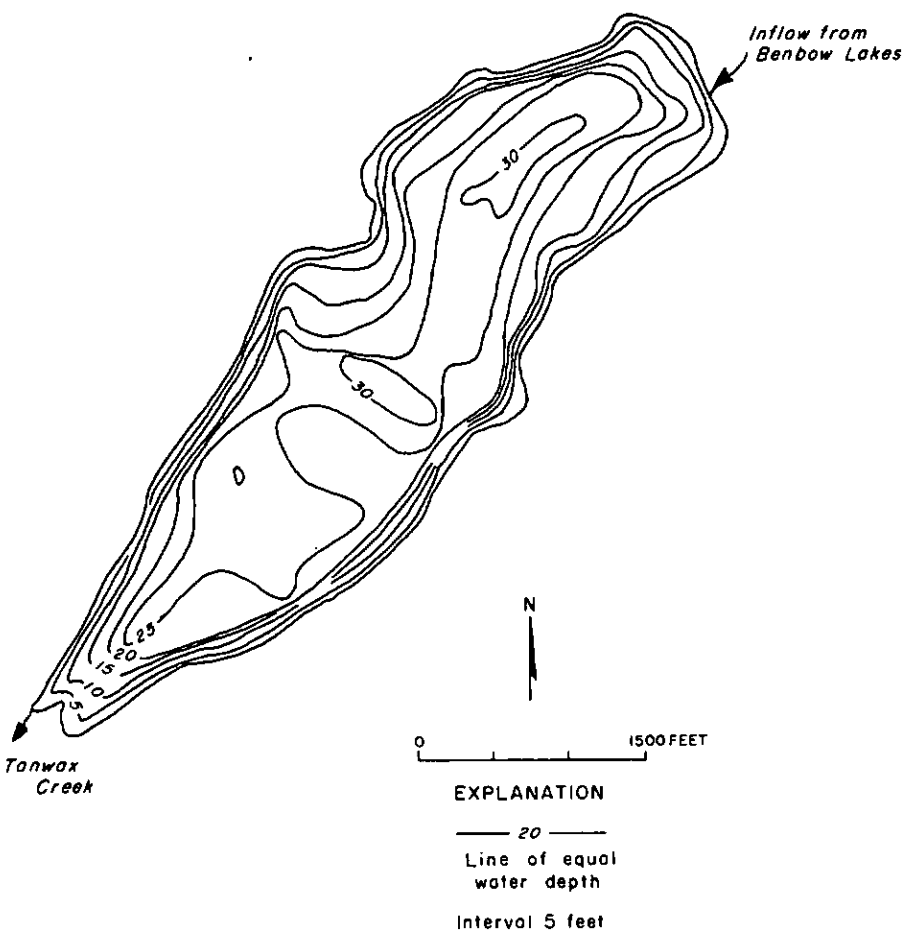


FIGURE 41. – Tanwax Lake near Kapowsin, surveyed by State Department of Game (map from Wolcott, 1965, p. 307). Zero depth datum is 600 ft. (msl).

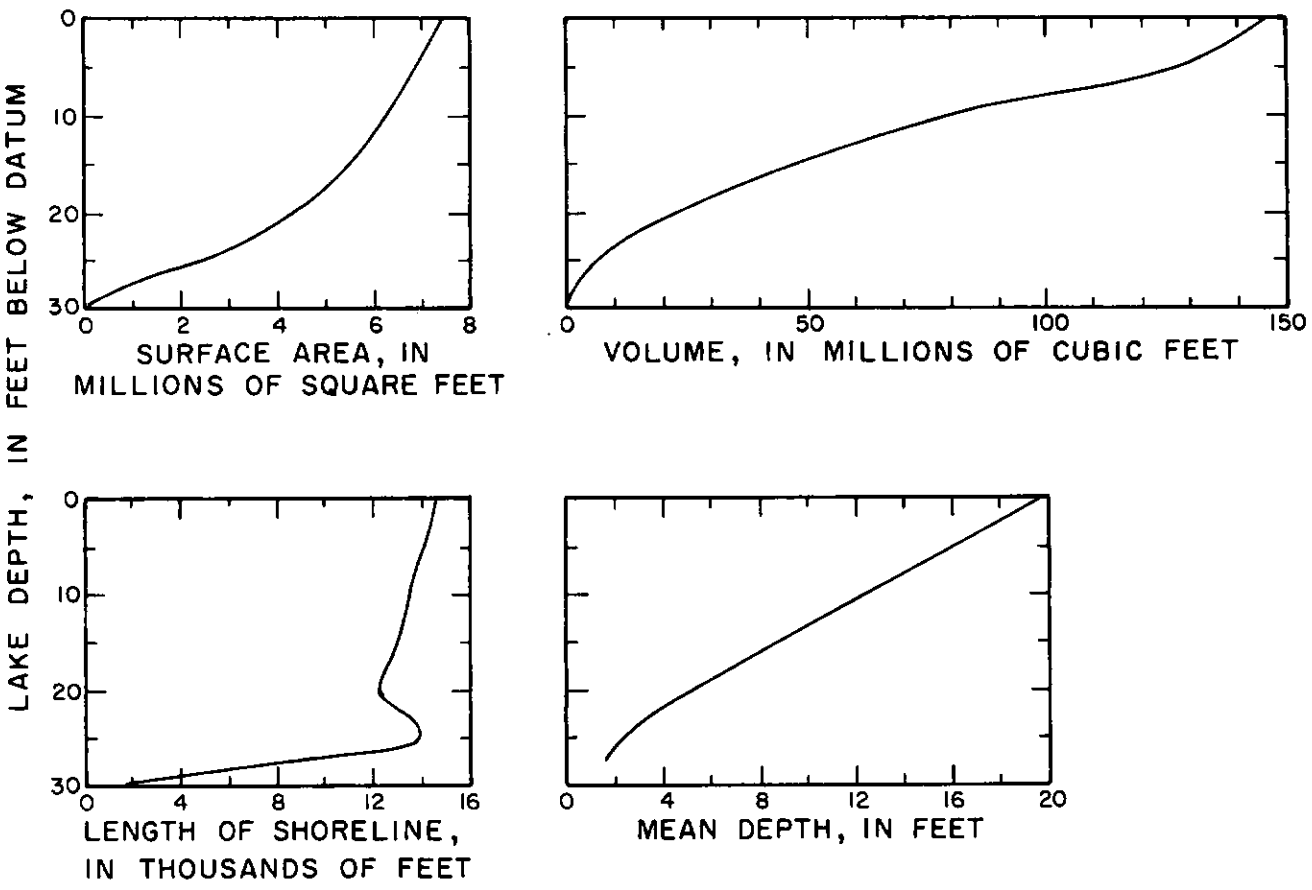


FIGURE 42. – Relations of surface area, volume, length of shoreline and mean depth to lake depth, Tanwax Lake near Kapowsin. Zero-depth datum is 600 feet above mean sea level, based on topographic-map altitude.

Figure 42 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 43 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

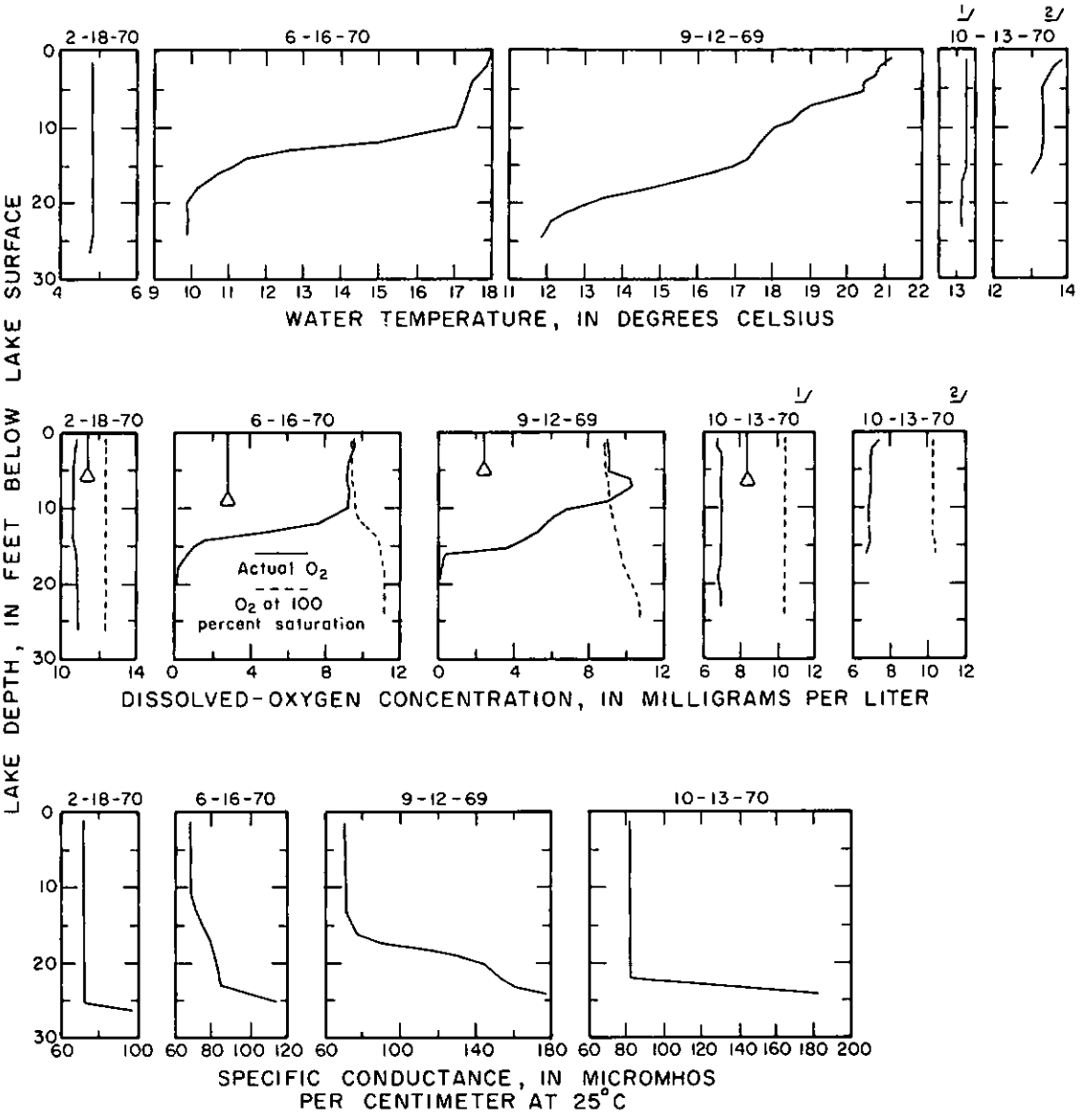


FIGURE 43. – Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Tanwax Lake near Kapowsin, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. Except as noted, all samples collected in deepest part of lake. Note the positive heterograde development of 114-percent oxygen saturation at 7 ft., for the DO profile for September 12.

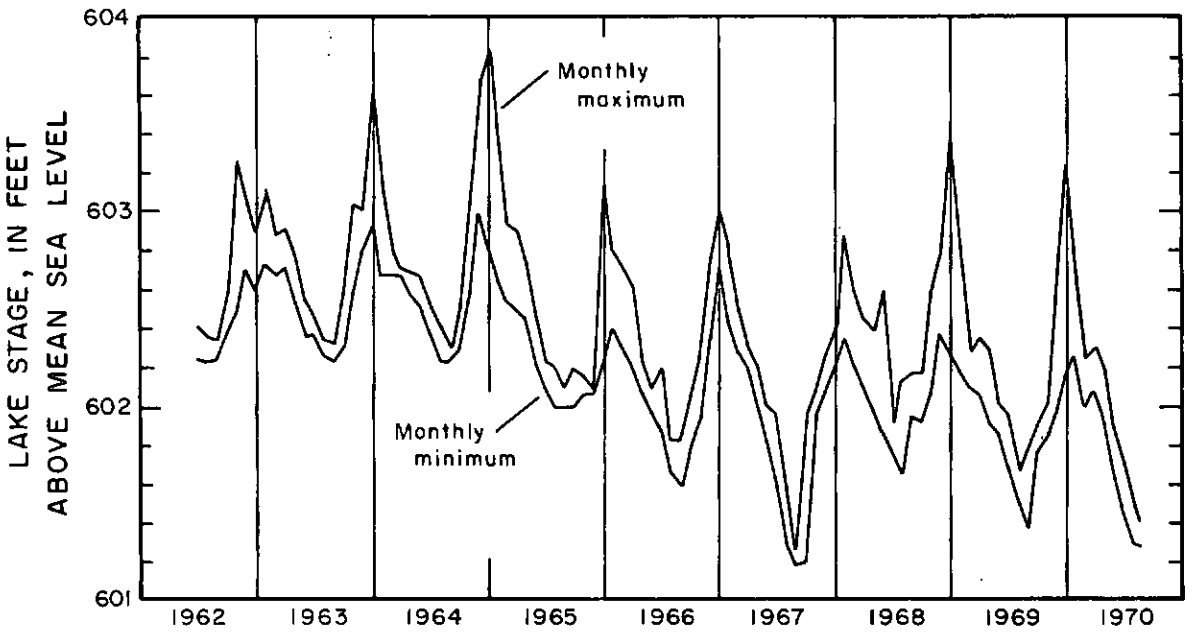


FIGURE 44. – Monthly maximum and monthly minimum lake stages, Tanwax Lake near Kapowsin, 1962-70.

Lake stages.--Lake level controlled by concrete dam at outlet.

Figure 44 shows a hydrograph of monthly maximum and minimum observed lake stages for period of record, 1962-70. Following are lake stages measured at the time of samplings, from a staff-gage datum of 602 ft msl.

Date	Lake stage (in ft above msl)
9-12-69	601.43
2-18-70	602.65
6-16-70	601.77
10-13-70	601.53

Surface-water inflow and outflow.--Lake spring fed and receives surface water from Ben Bow Lakes to north.

Outflow, through Tanwax Creek, is tributary to Nisqually River. Following are flow measurements made during the study:

Date	Inflow (in cfs)	Outflow (in cfs)
9-12-69	0.01	0
2-18-70	18.2	22.1
6-16-70	.35	1.0
10-13-70	.35	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-18-70	10-13-70
Depth of samples below surface, in ft	12	[a]3,12,and 21
Silica (SiO_2)	16	14
Iron (Fe)	--	.80
Manganese (Mn)	--	.19
Calcium (Ca)	5.6	--
Magnesium (Mg)	2.3	--
Sodium (Na)	3.5	--
Potassium (K)	.9	--
Bicarbonate (HCO_3)	30	42
Carbonate (CO_3)	0	0
Sulfate (SO_4)	.2	3.1
Chloride (Cl)	2.9	2.6
Fluoride (F)	.2	.1
Dissolved solids (residue at 180°C)	65	56
Hardness Ca-Mg	24	--
Hardness Noncarbonate	0	--
Alkalinity	25	34
pH, units	6.5	6.9
Color, Co-Pt units	50	30

[a]Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 43.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-12-69	1	0.006	0.016	0.04	--	--	--	0.25
2-18-70	12	.003	.026	.30	--	--	--	.52
6-16-70	20	.003	.390	.20	--	--	--	.32
10-13-70	3	.075	.098	.10	0.000	0.05	0.02	.17
10-13-70	12	.059	.082	.10	.000	.03	.02	.15
10-13-70	21	.049	.065	.20	.000	.02	.01	.23

Macrophytes.--Area of macrophytes 1.1 percent of lake area, October 13, 1970.

The dominant aquatic plants found were waterlily (Nymphaea and Nuphar) and watershield (Brasenia). Other plants found were pondweed (Potamogeton), waterweed (Elodea), watercelery (Vallisneria), horned pondweed (Zannichellia), and sedge (Cyperus).

Remarks.--Algal blooms noted on lake during October 13, 1970 sampling.

Conclusions.--Tanwax Lake has moderate to high biologic productivity. Macrophytes are fairly abundant and an algal bloom was noted on the lake. The lake has a relatively high winter nutrient and dissolved-solids concentration. In addition, a zone of oxygen supersaturation was observed in the metalimnion and an oxygen deficit occurs in the hypolimnion of the summer dissolved-oxygen profile. The lake has surface-water inflow and outflow which contribute to a fair flushing rate. The enrichment of the lake probably is partly natural, but the increased cultural and recreational use is causing an increased biologic productivity and eutrophication rate.

12089200. Harts Lake near McKenna

Location.--Surface-water outlet at lat 46°53'32", long 122°28'18"; lake in SE¼ sec. 6, NE¼ sec. 7, T.16 N., R.3 E., Pierce County.

Origin.--Kettle lake formed between till hills.

Basin geology.--Glacial-outwash plain with till deposits on upper basin.

Soils.--Gravelly clay loam on nearly level to moderately sloping bottom lands and low terraces.

Land use and cover.--Dairy farms and some residences.

Vegetal cover consists of grassland, second-growth fir and cedar, and deciduous trees. Approximately one-half the lakeshore is adjacent to grazing land, with a buffer of riparian vegetation. The other half, in a shoreward direction, is riparian vegetation, deciduous trees, and then conifers.

Population.--House count of October 1970 noted six lakeshore dwellings, three permanent and three seasonal residences, as compared to about 10 lakeshore dwellings in 1959 (estimated from U.S. Geological Survey topographic map).

Physical features of lake.--Littoral zone is composed of silt, muck, and some sand and small local patches of gravel.

Bathymetric map shown in figure 45 (Wolcott, 1965, p. 300).

Some morphometric parameters, at a lake stage of 349 ft (msl), are:

Drainage area	3.6 sq mi	Length of shoreline	8,480 ft
Altitude of deepest part of lake (using msl datum)	299 ft	Length of lake	2,870 ft
		Breadth of lake	2,400 ft
Surface area	5.27 million sq ft	Shoreline configuration	1.04
Lake volume	136.3 million cu ft	Development of volume	0.52
Mean depth	25.8 ft	Relative depth	1.92 percent
Maximum depth	50.0 ft	Mean slope	3°08'

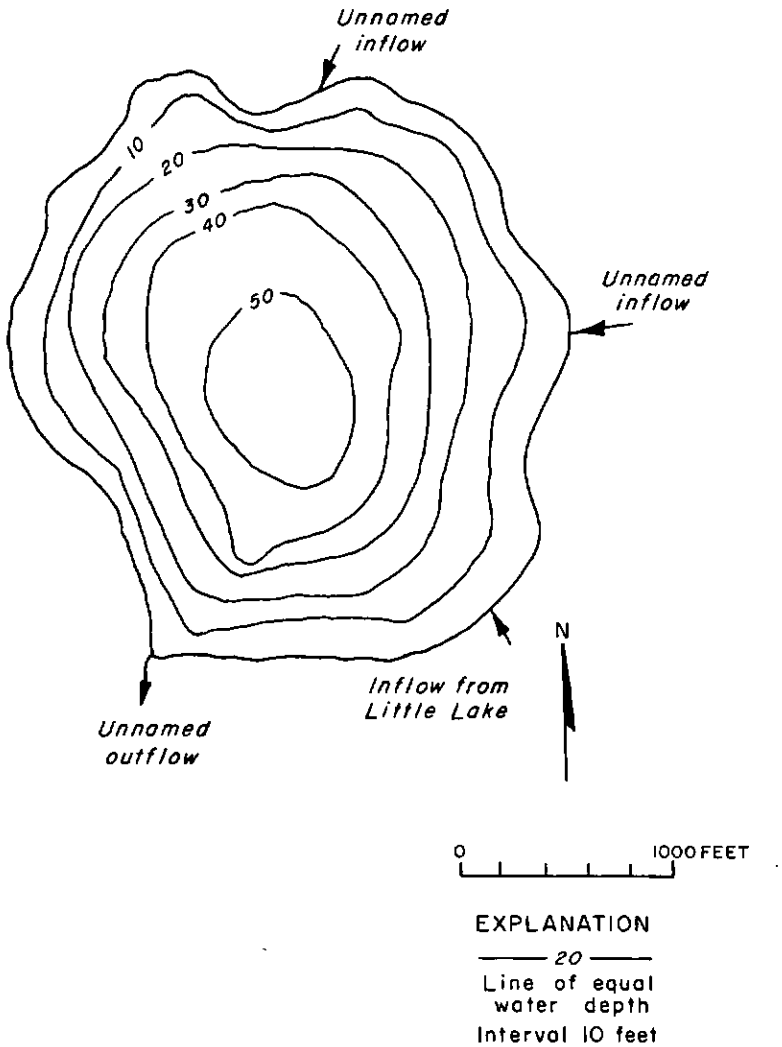


FIGURE 45. – Harts Lake near McKenna, surveyed June 1, 1953 by State Department of Game (map from Wolcott, 1965, p. 300). Zero-depth datum is 349 ft. (msl).

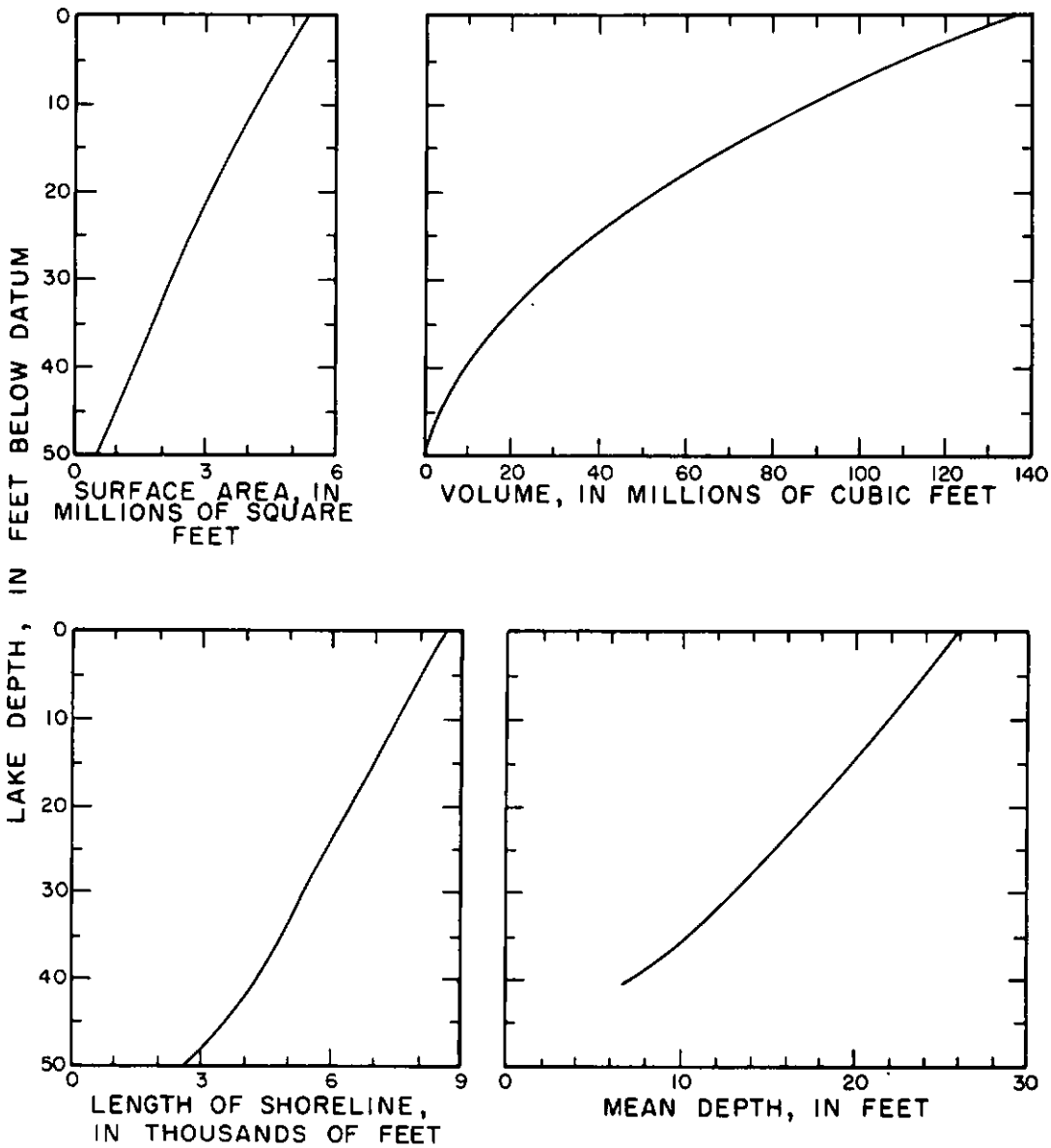


FIGURE 46. – Relations of surface area; volume, length of shoreline, and mean depth to lake depth, Harts Lake near McKenna. Zero-depth datum is 349 feet above mean sea level, based on topographic-map altitude.

Figure 46 shows relations of area, volume, length of shoreline, and mean depth to stage. Figure 47 shows profiles of DO concentration and water temperature, as well as Secchi-disc transparency depths.

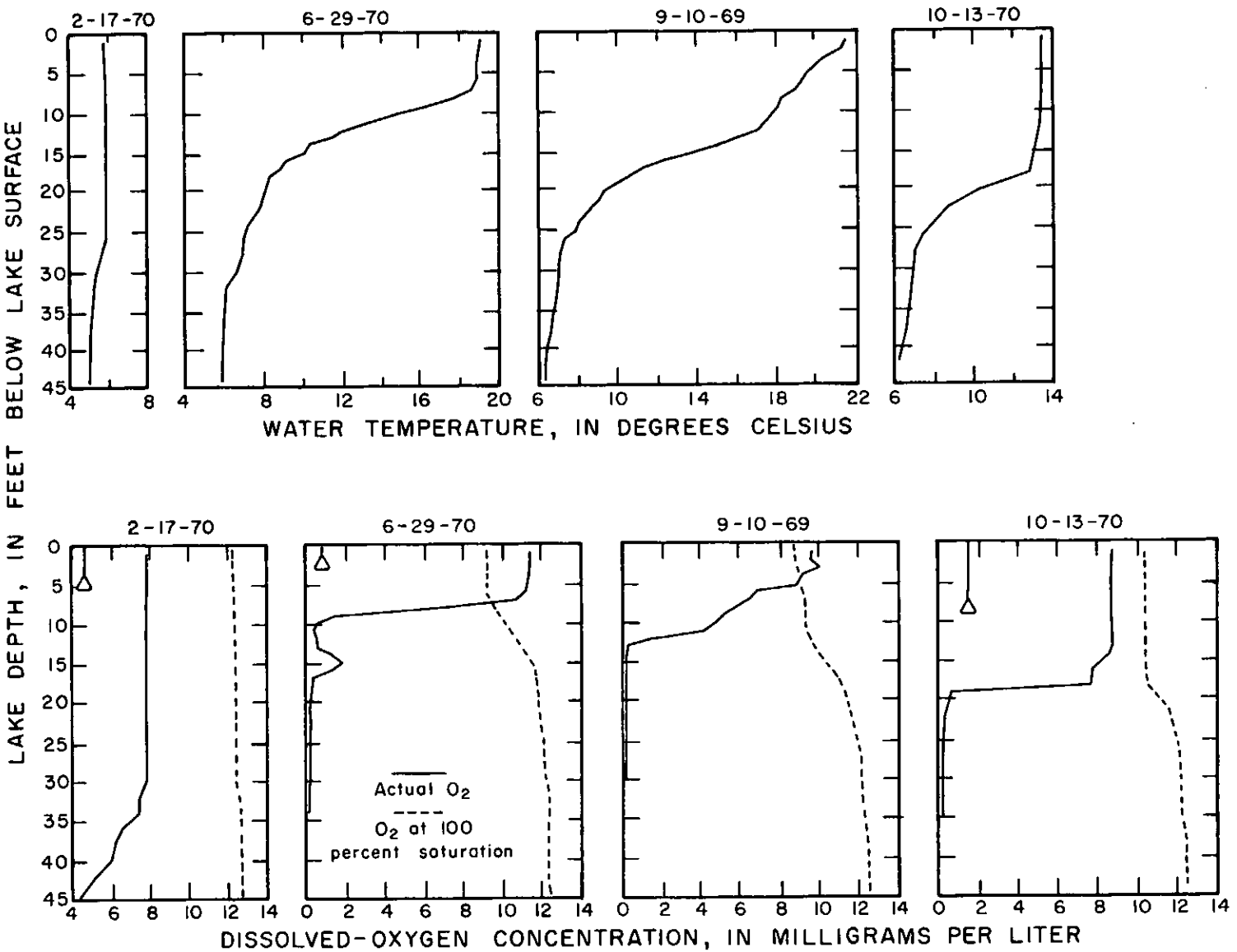


FIGURE 47. – Selected seasonal profiles of lake temperature and DO concentration, Harts Lake near McKenna, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles.

Lake stages.--Miscellaneous measurements of lake stages from arbitrary datum are:

Date	Lake stage (in ft above msl)
9-10-69	349.15
2-17-70	349.93
6-29-70	349.17
10-13-70	348.46
11-10-70	348.56

Surface-water inflow and outflow.--Three intermittent surface-water streams flow into lake, one from the north, one from the southwest, and one from Little Lake on the south. Streams from the south and southeast partially drain pasture-land. Outflow is through an unnamed creek on the southwest side of the lake. Miscellaneous measurements of inflow and outflow are listed below.

Date	Inflow (in cfs)	Outflow (in cfs)
2-17-70	6.34	14.3
6-29-70	0	.49
10-13-70	0	.88

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-17-70	10-13-70	10-13-70
Depth of samples below surface, in ft	30	[a]3 and 18.5	40
Silica (SiO_2)	21	17	24
Iron (Fe)	--	.00	4.5
Manganese (Mn)	--	.05	.66
Calcium (Ca)	11	--	--
Magnesium (Mg)	5.8	--	--
Sodium (Na)	6.1	--	--
Potassium (K)	2.2	--	--
Bicarbonate (HCO_3)	62	76	85
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	4.0	.4	.2
Chloride (Cl)	7.5	4.8	4.8
Fluoride (F)	.3	.2	.2
Dissolved solids (residue at 180°C)	110	104	134
Hardness Ca-Mg	52	--	--
Hardness Noncarbonate	1	--	--
Alkalinity	51	62	70
pH, units	6.8	7.3	6.7
Color, Co-Pt units	50	20	100

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 48.

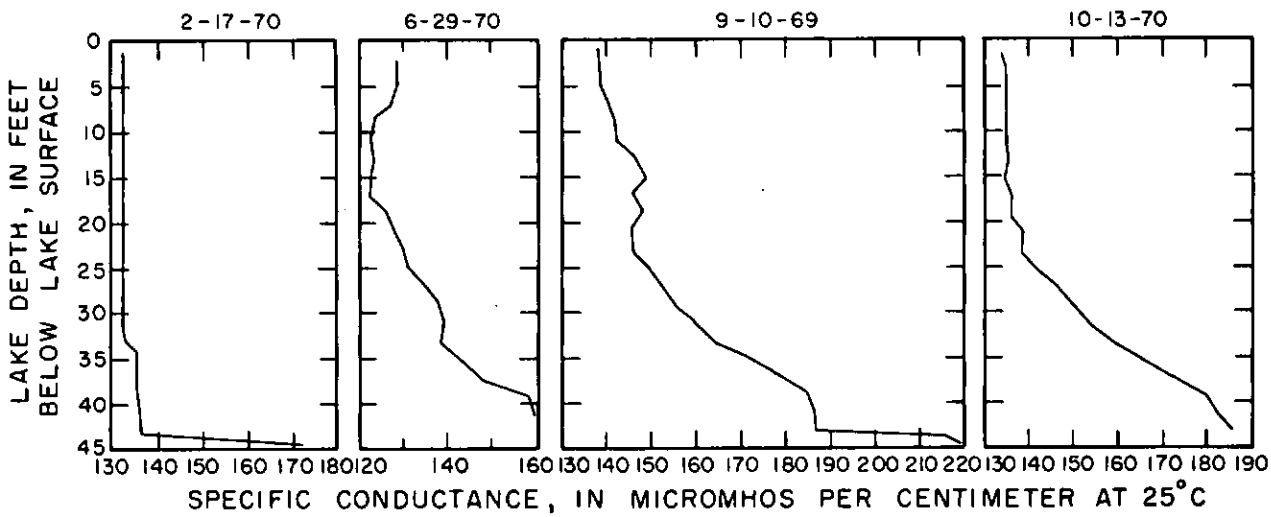


FIGURE 48. – Selected seasonal profiles of specific conductance, Harts Lake near McKenna.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-10-69	1	0.003	0.020	0.04	--	--	--	0.59
2-17-70	30	.065	.200	.95	--	--	--	1.10
6-29-70	43	.820	.820	1.80	--	--	--	2.10
10-13-70	3	.033	.049	.20	0.130	0.03	0.03	.39
10-13-70	18.5	.033	.042	.09	.003	.03	.03	.16
10-13-70	40	.390	.490	.13	.000	3.30	1.10	4.50

Macrophytes.--Area of macrophytes 2.8 percent of lake area, October 13, 1970.

The dominant aquatic plants found were waterlily (Nuphar and Nymphaea), watershield (Brasenia), cattail (Typha), and a large-leaf pondweed (Potamogeton).

Remarks.--Part of a hill, on the north end of the lake, has been excavated.

Algal blooms were observed on the lake during September 10, 1969, and again on October 13, 1970. On the east side of the lake the vegetation, in the form of peat and other organic material, has encroached as much as 20 ft into the lake.

Conclusions.--Only a few dwellings exist on the shore of Harts Lake; most of the shoreline is adjacent to dairy pastureland and the littoral zone is composed mainly of muck and mud with some sand. The pastureland and littoral zone are probably the main source of the lake's enrichment. The biologic productivity of the lake is evidenced by high winter nutrient content, high color, high specific conductance, very low water transparencies, oxygen depletion in the hypolimnion during summer stratification, an abundance of macrophytes, and an observed algal bloom.

12090300. American Lake near Tillicum

Location.--Lake outlet at lat 47°06'30", long 122°35'18"; lake in secs. 15, 16, 17, 20, 21, and 29, T.19 N., R.2 E., Pierce County.

Origin.--One of a chain of kettle lakes.

Lake shape is partly controlled by earlier deposited till hills to the north and west. Gravelly and Steilacoom Lakes are also part of the kettle chain. The lakes were probably formed in a preglacial stream channel.

Basin geology.--Gravel deposit with till hills.

Soils.--Gently undulating gravelly sandy loam soils.

Land use and cover.--Mainly urban, consisting of residential areas, country clubs, a hospital, and military housing.

Vegetal cover consists of lawns, deciduous and conifer trees, and some marshland with associated plant growth.

Population.--House count of October 1970 noted about 250 structures within 300 ft of the water's edge.

Buildings and (or) recreational facilities occupy 80 percent of lakeshore or near lakeshore. The north end of lake has the greatest population density.

Physical features of lake.--Littoral zone of lake is composed mainly of gravel.

There are four islands in the lake, they are, from largest to smallest, Silcox, Barlow, Beard, and Short. Total area of islands is 664,000 sq ft.

Bathymetric map shown in figure 49 (Wolcott, 1965, p. 323).

Some morphometric parameters, at a lake stage of 235 ft (msl), are:

Drainage area--------- 24.5 sq mi	Length of shoreline- 62,200 ft
Altitude of deepest part of lake (using msl datum)---------- 143 ft	Length of lake------ 17,040 ft
	Breadth of lake----- 5,040 ft
Surface area-- 49.4 million sq ft	Shoreline configuration-- 2.49
Lake volume-- 2,624 million cu ft	Development of volume-----0.59
Mean depth---------- 53 ft	Relative depth---- 1.1 percent
Maximum depth---------- 92 ft	Mean slope---------- 4°40'

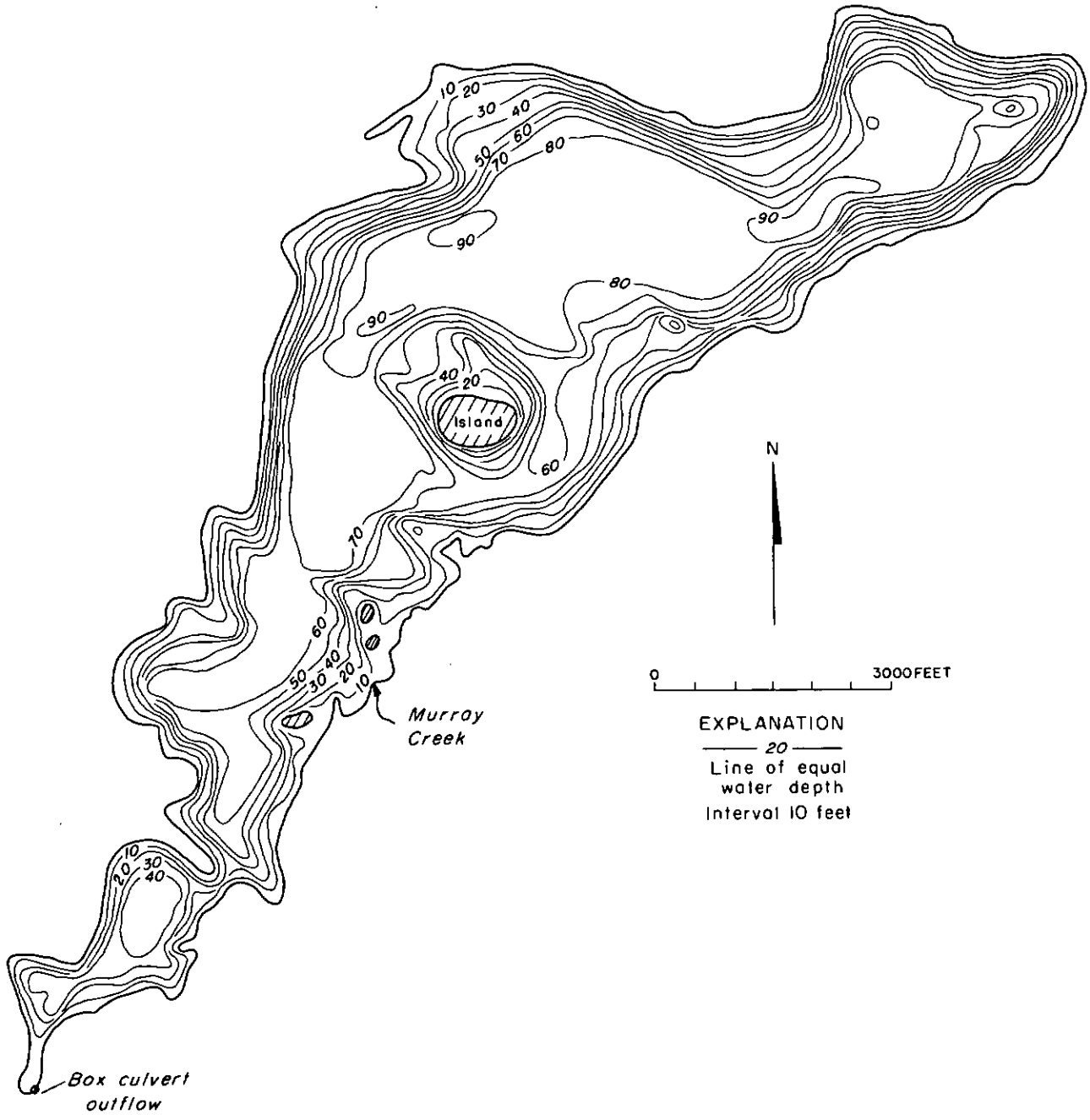


FIGURE 49. – American Lake near Tillicum, surveyed May 24, 1953 by State Department of Game (map from Wolcott, 1965, p. 323). Zero-depth datum is 235 ft. (msl).

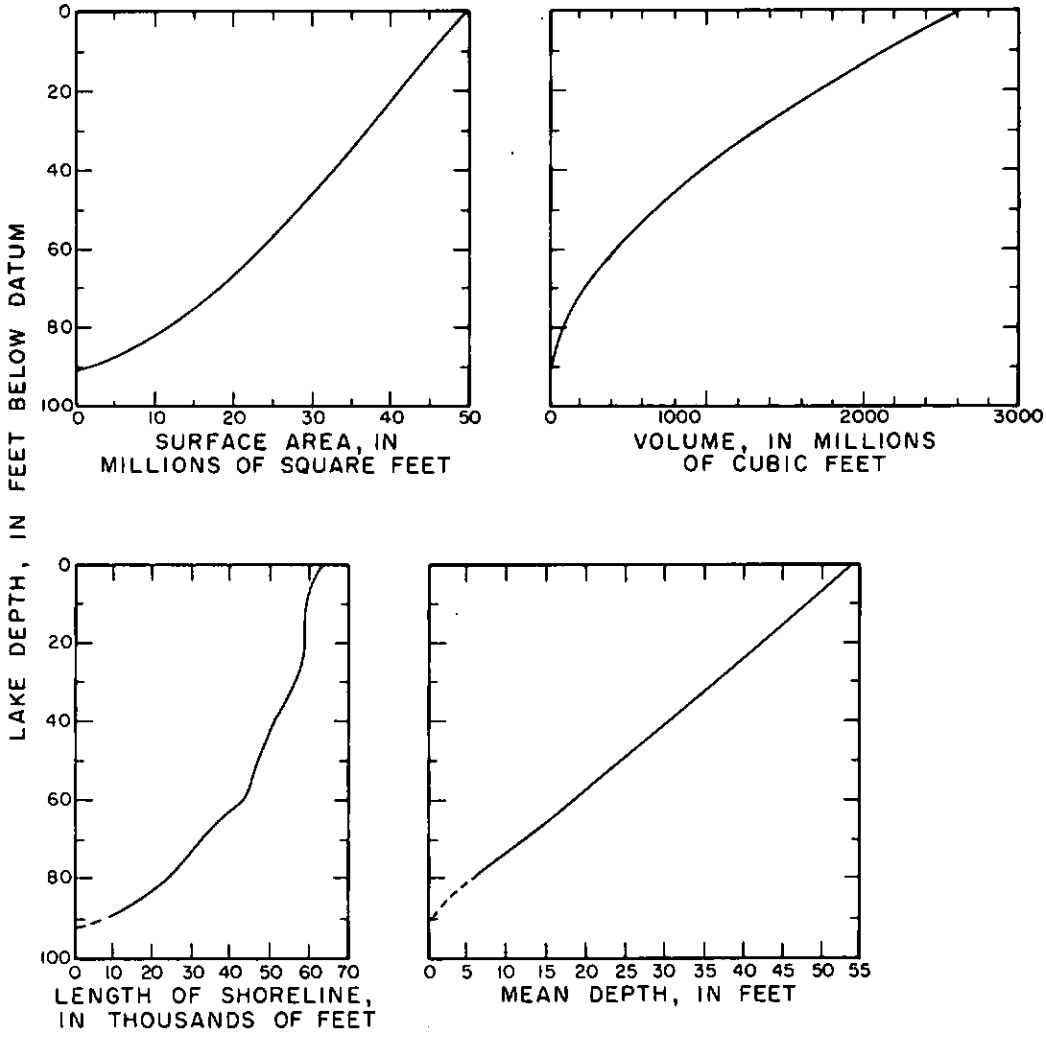


FIGURE 50. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, American Lake near Tillicum. Zero-depth datum is 235 feet above mean sea level, based on topographic-map altitude.

Figure 50 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 51 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

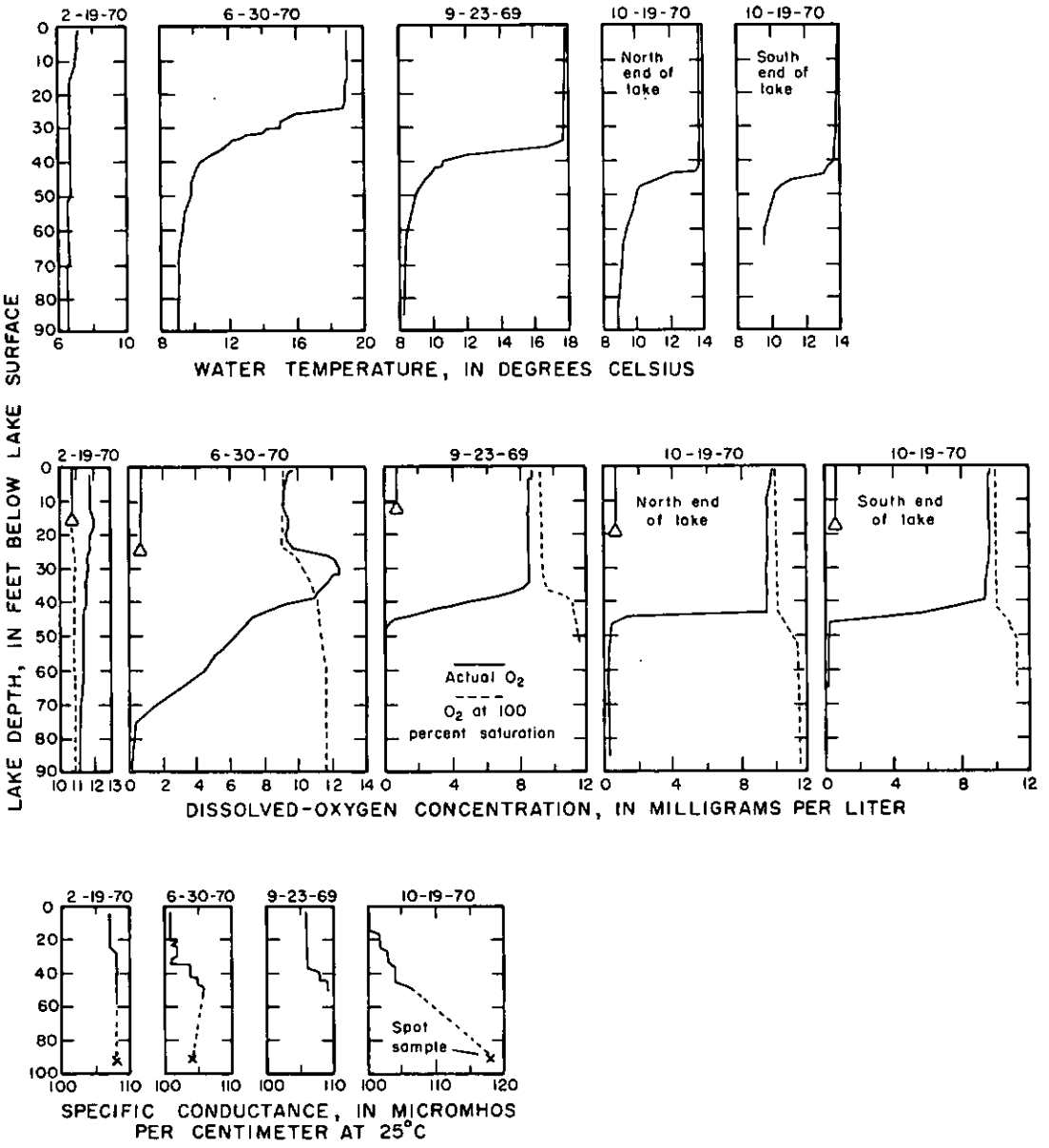


FIGURE 51. – Selected profiles of lake temperature, DO concentration, and specific conductance, American Lake near Tillicum, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. DO profile for June 30 shows positive heterograde development with 120-percent oxygen saturation at 25 ft. depth.

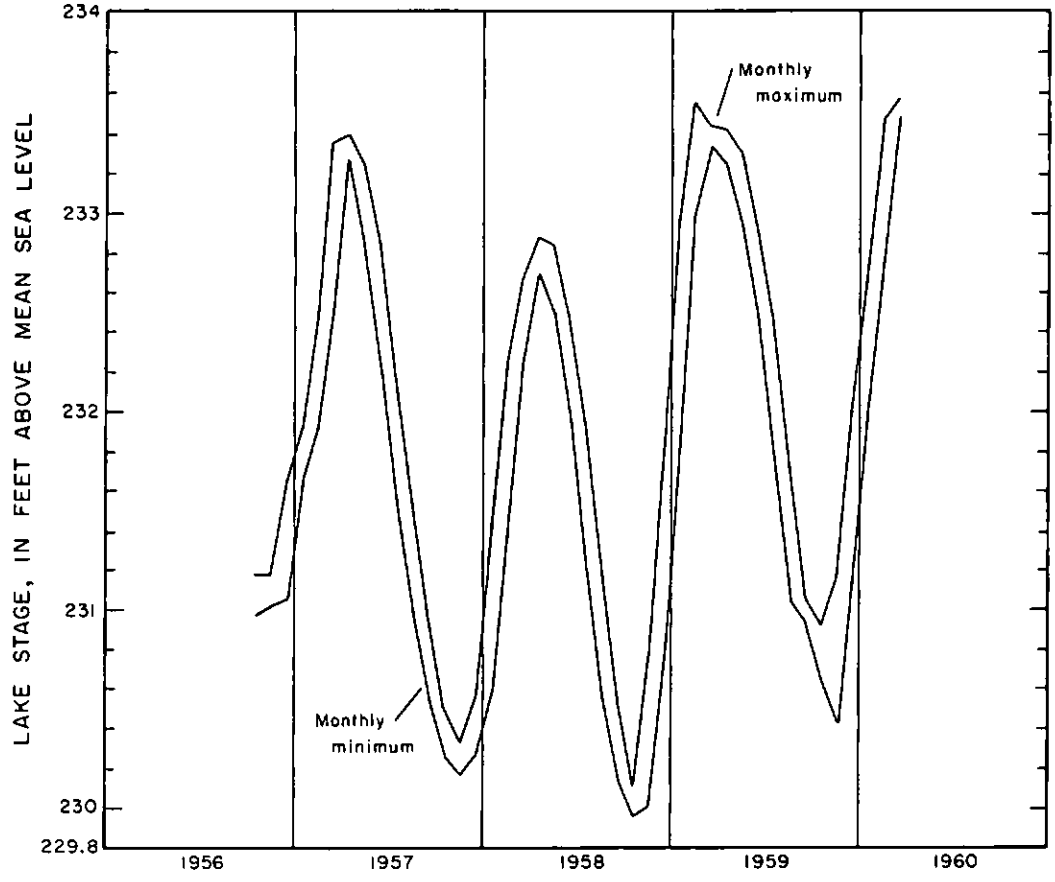


FIGURE 52. – Observed monthly maximum and monthly minimum lake stages, American Lake near Tillicum, 1956-60.

Lake stages.--Hydrograph of monthly maximum and minimum lake stages during 1956-60 shown in figure 52.

A maximum elevation of the lake is controlled at 233 ft by means of a drop-entrance box culvert at the west end of the lake (installed May 14, 1956). The culvert extends from the head of the lake into Sequallitchew Creek basin.

Miscellaneous measurements of lake stages (at staff-gage datum of 231 ft msl) are:

Date	Lake stage (in ft above msl)
9-23-69	230.36
2-19-70	232.19
6-30-70	231.39
10-19-70	229.12
11- 9-70	229.06

Surface-water inflow and outflow.--No natural lake outlet exists and a culvert has been installed to guard against flooding conditions.

Some seepage from the lake appears in Sequallitchew Creek channel, below the culvert outlet, when the lake elevation is below the top of the drop-entrance culvert.

Surface-water inflow to the lake comes from Murray Creek on the east side of the lake. Additional inflow is received from ground water, precipitation, and local run-off. Miscellaneous measurements of inflow and outflow are listed below.

Date	Inflow (in cfs)	Outflow (in cfs)
9-23-69	--	0
2-19-70	10.6	0
6-30-70	2.53	0
10-19-70	1.33	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated				
	North end of lake			South end of lake	
Date of sampling	2-19-70	10-19-70	10-19-70	10-19-70	10-19-70
Depth of samples below surface, in ft	50	3	[a]44 and 87	[a]3 and 44	60
Silica (SiO_2)	.4	.1	4.8	2.0	4
Iron (Fe)	--	.04	.16	.02	.10
Manganese (Mn)	--	.00	.02	.01	.03
Calcium (Ca)	11	--	--	--	--
Magnesium (Mg)	3.4	--	--	--	--
Sodium (Na)	5.0	--	--	--	--
Potassium (K)	.8	--	--	--	--
Bicarbonate (HCO_3)	48	50	52	50	53
Carbonate (CO_3)	0	0	0	0	0
Sulfate (SO_4)	7.8	8.0	9.7	7.4	8.4
Chloride (Cl)	3.7	3.3	3.4	3.4	3.5
Fluoride (F)	.1	.1	.1	.1	.1
Dissolved solids (residue at 180°C)	58	62	62	55	63
Hardness Ca-Mg	42	--	--	--	--
Hardness Noncarbonate	2	--	--	--	--
Alkalinity	39	41	42	41	43
pH, units	6.8	7.5	6.8	7.4	6.9
Color, Co-Pt units	5	0	0	0	0

[a] Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 51.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
2-23-69[a]	1	0.000	0.000	0.02	--	--	--	0.09
2-19-70[a]	50	.003	.013	.04	--	--	--	.04
6-30-70[a]	90	.003	.036	.20	--	--	--	.61
10-19-70[a]	3	.006	.013	.07	0.000	0.06	0.02	.18
10-19-70[a]	44	.006	.010	.00	.046	.06	.02	.13
10-19-70[a]	87	.160	.200	.20	.000	1.30	.33	1.80
10-19-70[b]	3	.006	.006	.20	.012	.07	.02	.30
10-19-70[b]	44	.006	.010	.10	.043	.02	.02	.18
10-19-70[b]	60	.065	.088	.60	.260	.18	.07	1.10

[a]Sampled on north end of lake.

[b]Sampled on south end of lake.

Macrophytes.--Area of macrophytes 0.07 percent of lake area, October 19, 1970.

Aquatic-plant growth is not excessive in the lake. The dominant macrophyte found was pondweed (Potamogeton). Also found but in minor quantities were waterweed (Elodea), water-lily (Nuphar), sedge (Cyperus), and watercelery (Vallisneria).

Conclusions.--The urban-environment setting of American Lake probably is the major cause of its medium level of biologic productivity and trophic nature. Because of the lake's size and geologic setting, with flushing occurring through both surface- and ground-water discharges, the buildup of limiting nutrients is reduced. The biologic productivity of the lake is evidenced by a moderate winter nutrient content (however, with nitrogen found to be fairly high), by moderate to high specific conductance, and by a zone of oxygen-supersaturation in the metalimnion and oxygen depletion in the hypolimnion of the summer dissolved-oxygen profiles.

12090690. Gravelly Lake near Tillicum

Location.--Southernmost tip of lake at lat 47°08'32", long 122°31'45"; lake in sec. 10, T.19 N., R.2 E., Pierce County.

Origin.--Kettle lake in a chain of kettles formed in preglacial north-trending drainage channel.

Basin geology.--Gravel deposit with till hills.

Soils.--Gently undulating gravelly sandy loam soils.

Land use and cover.--Fairly dense urban development.

The vegetal cover consists of lawns, evergreens, and deciduous trees.

Population.--Surrounded by homes.

Many of the homes are set back from the shore by as much as 600 ft with lawns extending to the lakeshore.

Physical features of lake.--Littoral zone of lake composed of gravel. However, there are local areas of sand and silt with interspersed gravel-size rocks.

Bathymetric map of Gravelly Lake is shown in figure 53.

Some morphometric parameters, at a lake stage of 220 ft (msl), are:

Drainage area-------- 0.66 sq mi	Length of shoreline- 11,010 ft
Altitude of deepest part of lake (using msl datum)---------- 165 ft	Length of lake------- 3,760 ft
	Breadth of lake------ 2,540 ft
Surface area- 6.96 million sq ft	Shoreline configuration-- 1.18
Lake volume--- 261 million cu ft	Development of volume---- 0.68
Mean depth---------- 37.5 ft	Relative depth--- 1.85 percent
Maximum depth---------- 55 ft	Mean slope---------- 4°28'

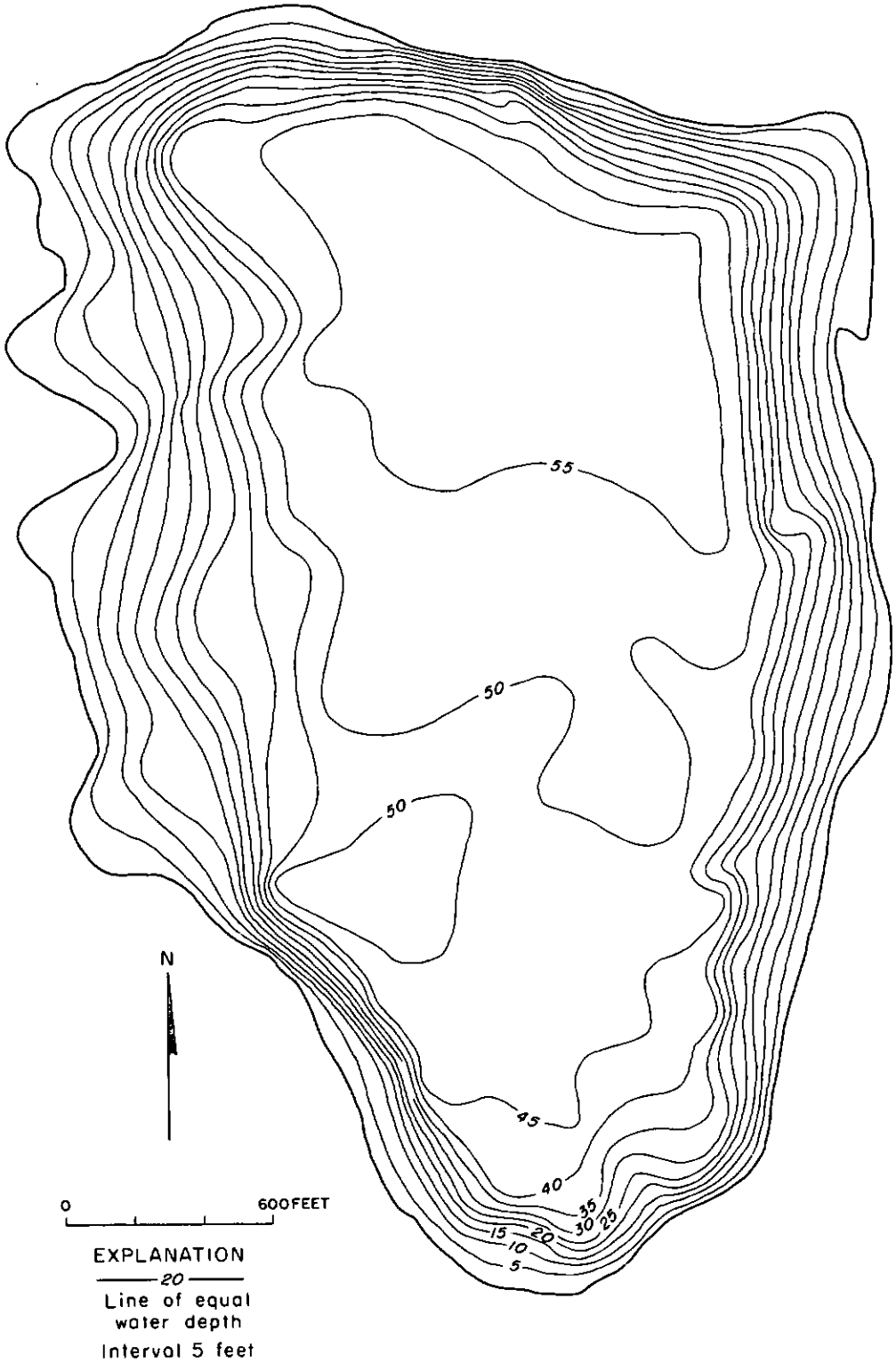


FIGURE 53. – Gravelly Lake near Tillicum, with lake bottom shown by 5-foot contours, based on mean sea level datum and on 17 cross-sectional depth profiles. Lake stage is 220 feet above mean sea level. Mapped by U.S. Geological Survey in July 1970.

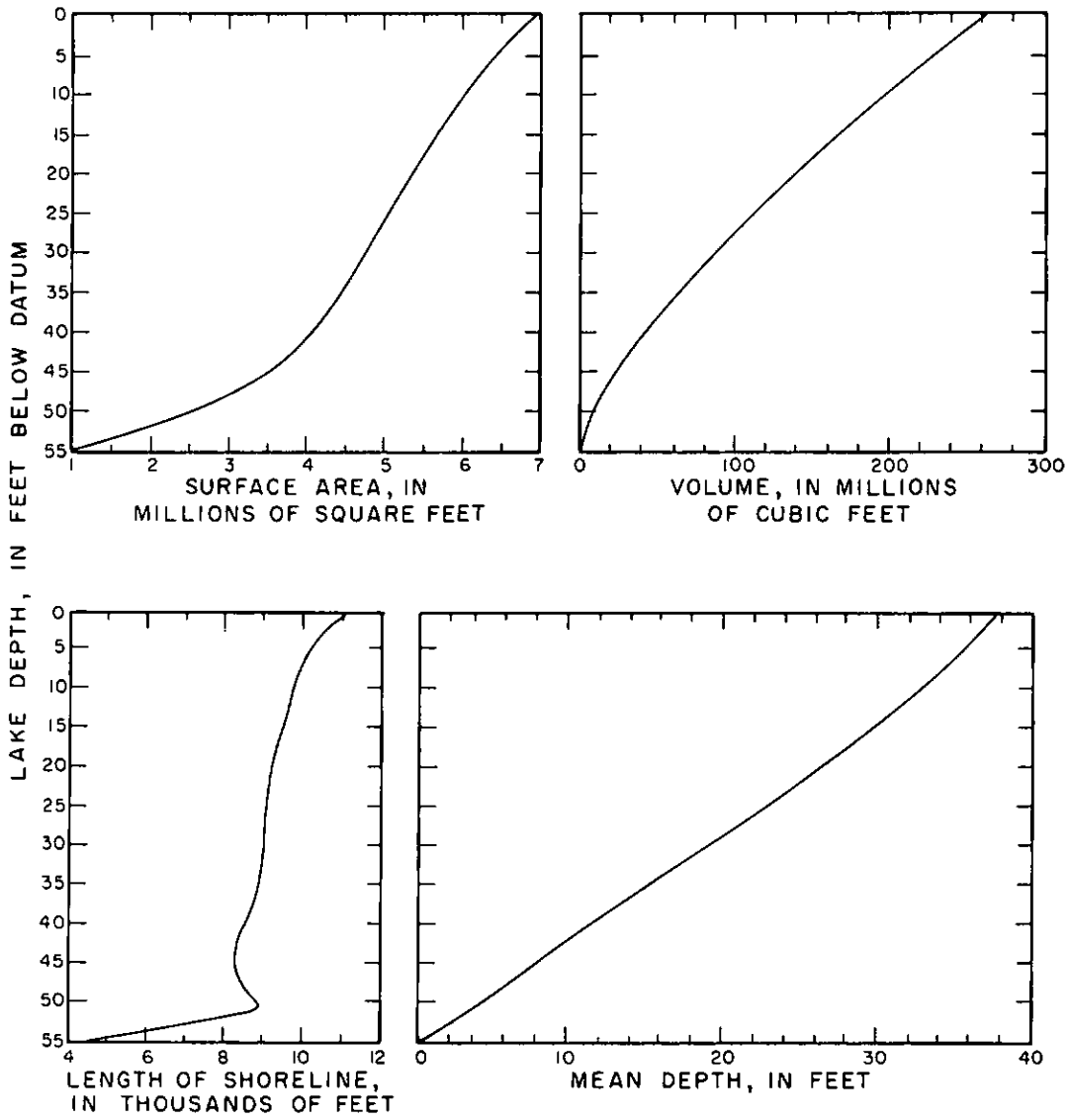


FIGURE 54. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Gravelly Lake near Tillicum. Zero-depth datum is 220 feet above mean sea level, based on topographic-map altitude.

Figure 54 shows relations of area, volume, length of shoreline, and mean depth to stage. Figure 55 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

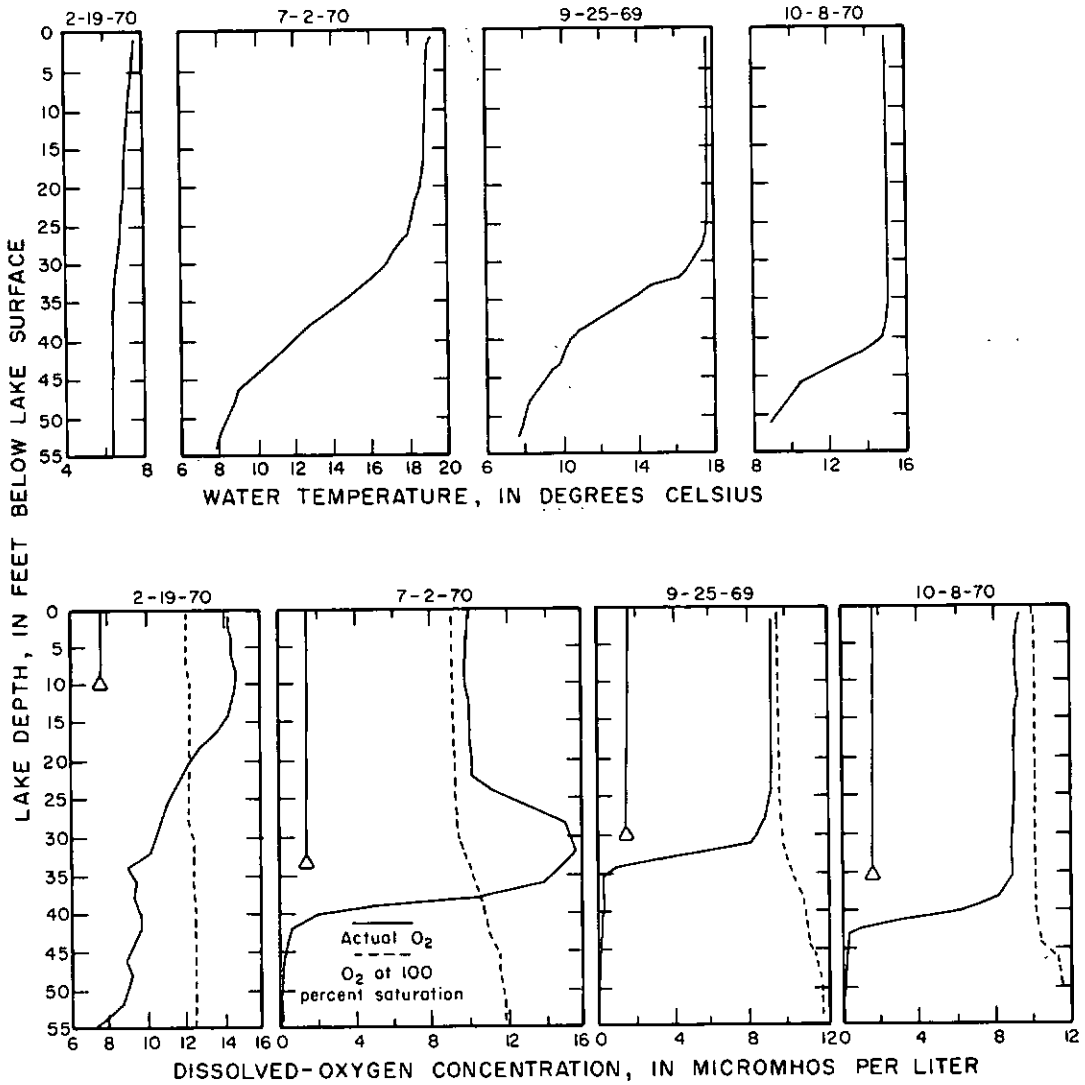


FIGURE 55. – Selected seasonal profiles of lake temperature and DO concentration, Gravelly Lake near Tillicum, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. DO profile for July 2 shows an excellent positive heterograde development with a 161-percent oxygen saturation at 32 ft.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-25-69	218.82
2-19-70	222.16
7- 2-70	220.91
7-24-70	219.95
10- 8-70	217.53

Surface-water inflow and outflow.--Lake is in closed basin.

There is no surface-water inflow or outflow channel. The lake stage is increased by precipitation, local storm runoff, and ground water, and declines because of evapotranspiration and ground-water seepage.

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-19-70	10-8-70	10-8-70
Depth of samples below surface, in ft	25	[a]3 and 38	49
Silica (SiO_2)	8.4	12	18
Iron (Fe)	--	.00	.12
Manganese (Mn)	--	.00	.00
Calcium (Ca)	13	13	15
Magnesium (Mg)	5.2	5.5	5.5
Sodium (Na)	6.0	6.2	6.2
Potassium (K)	1.2	1.2	1.8
Bicarbonate (HCO_3)	62	65	83
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	10	11.0	5.0
Chloride (Cl)	4.7	4.6	4.8
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	85	90	115
Hardness Ca-Mg	54	55	60
Hardness Noncarbonate	3	2	0
Alkalinity	51	53	68
pH, units	6.8	7.2	7.2
Color, Co-Pt units	5	0	5

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 56.

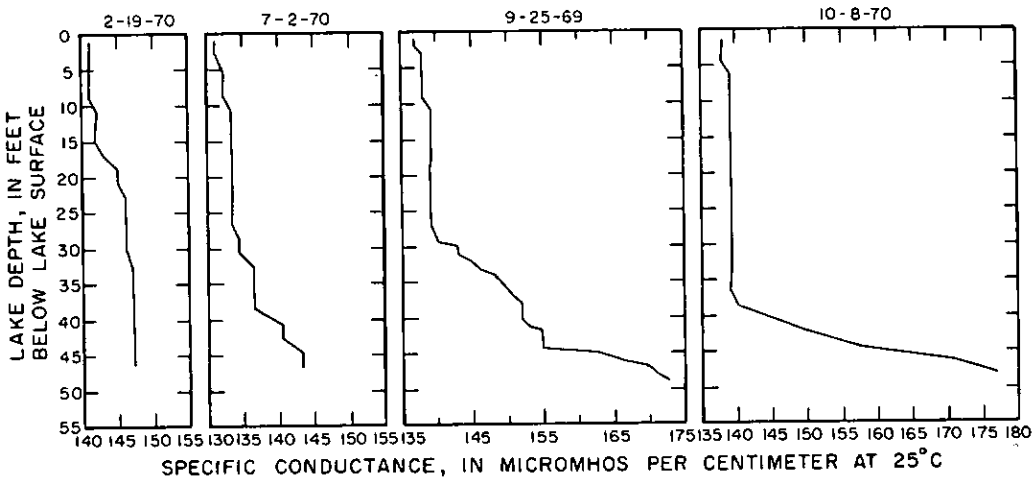


FIGURE 56. – Selected seasonal profiles of specific conductance, Gravelly Lake near Tillicum, 1969-70.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-25-69	1	0.003	0.006	0.40	--	--	--	0.50
2-19-70	25	.003	.026	.70	--	--	--	.77
7- 2-70	52	.240	.250	.04	--	--	--	.14
10- 8-70	3	.026	.026	.40	0.018	0.11	0.04	.57
10- 8-70	38	.036	.036	.40	.061	.12	.03	.61
10- 8-70	48	.780	.780	2.70	.000	3.10	2.20	8.00

Macrophytes.--Survey conducted on October 8, 1970.

No emergent aquatic plants were noted in the lake. However, by grappling, two varieties of submergent plants were found: (1) pondweed (Potamogeton) and (2) muskgrass (Chara vulgaris). The submergent aquatics were found in the west-central side of the lake.

Conclusions.--Fairly high biologic productivity in Gravelly Lake is indicated by the high values of specific conductance, the high winter nutrient content (especially nitrogen), the summer development of a zone of oxygen-supersaturation in the metalimnion, and an oxygen deficit in the hypolimnion of the summer dissolved-oxygen profile. The lake's urban environment probably has an enriching effect. The lake is being treated with algacides and herbicides which help to lessen the rate of eutrophication.

12090990. Steilacoom Lake near Steilacoom

Location.--Surface-water outlet at lat 47°10'40", long 122°32'04"; parts of lake located in sec. 34, T.20 N., R.2 E., and sec. 3, T.19 N., R.2 E., Pierce County.

Origin.--Kettle lake, one of a southwest-trending kettle chain.

The shape of the lake was partly a result of a preglacial drainage channel and till hills to west.

Basin geology.--Gravel deposits with till hills.

Soils.--Shallow and moderately deep, gently undulating gravelly sandy loam soils.

Land use and cover.--Fairly dense urban development.

Vegetal cover consists of lawns and scattered stands of deciduous and conifer trees.

Population.--In October 1970 approximately 287 lakeshore or nearshore dwellings.

Physical features of lake.--Littoral zone is mainly gravel with local areas of muck and silt.

Bathymetric map shown in figure 57 (Wolcott, 1965, p. 328).

Some morphometric parameters, at a lake stage of 210 ft (msl), are:

Drainage area	89.4 sq mi	Length of shoreline	30,100 ft
Altitude of deepest part of lake (using msl datum)	190 ft	Length of lake	6,000 ft
		Breadth of lake	3,310 ft
Surface area	13.8 million sq ft	Shoreline configuration	2.28
Lake volume	154 million cu ft	Development of volume	0.56
Mean depth	11.1 ft	Relative depth	0.5 percent
Maximum depth	20 ft	Mean slope	1°38'

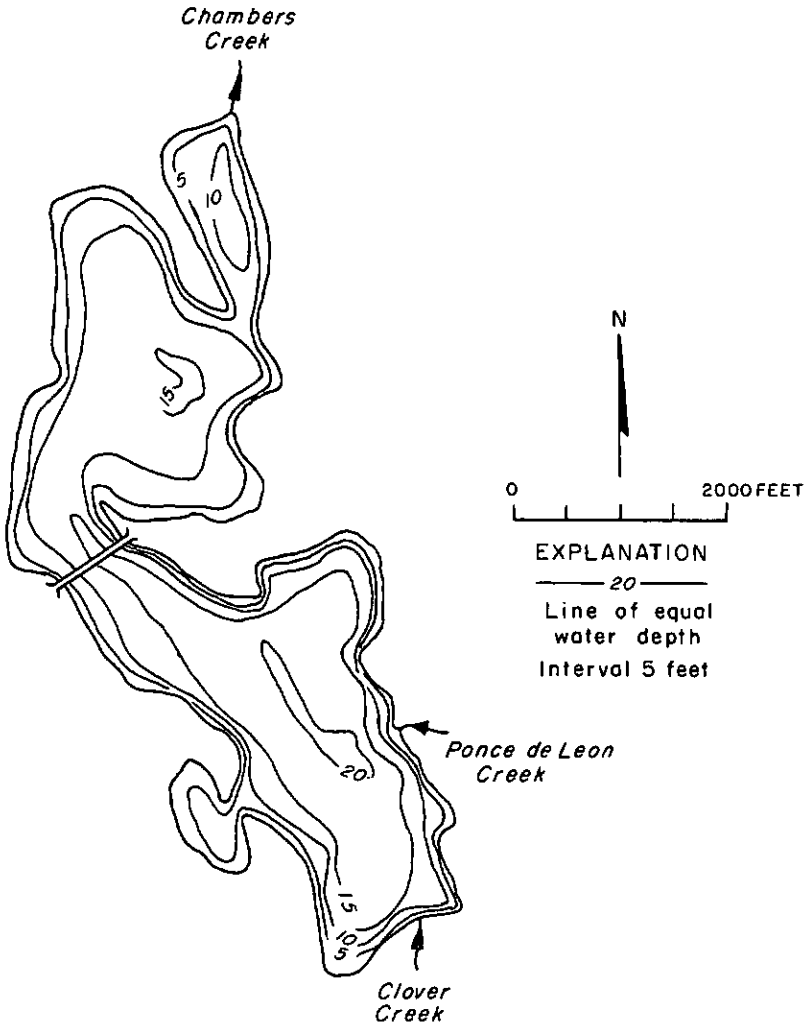


FIGURE 57. – Steilacoom Lake near Steilacoom, surveyed February 3 and June 2, 1950 by State Department of Game (map from Wolcott, 1965, p. 328). Zero-depth datum is 210 ft. (msl).

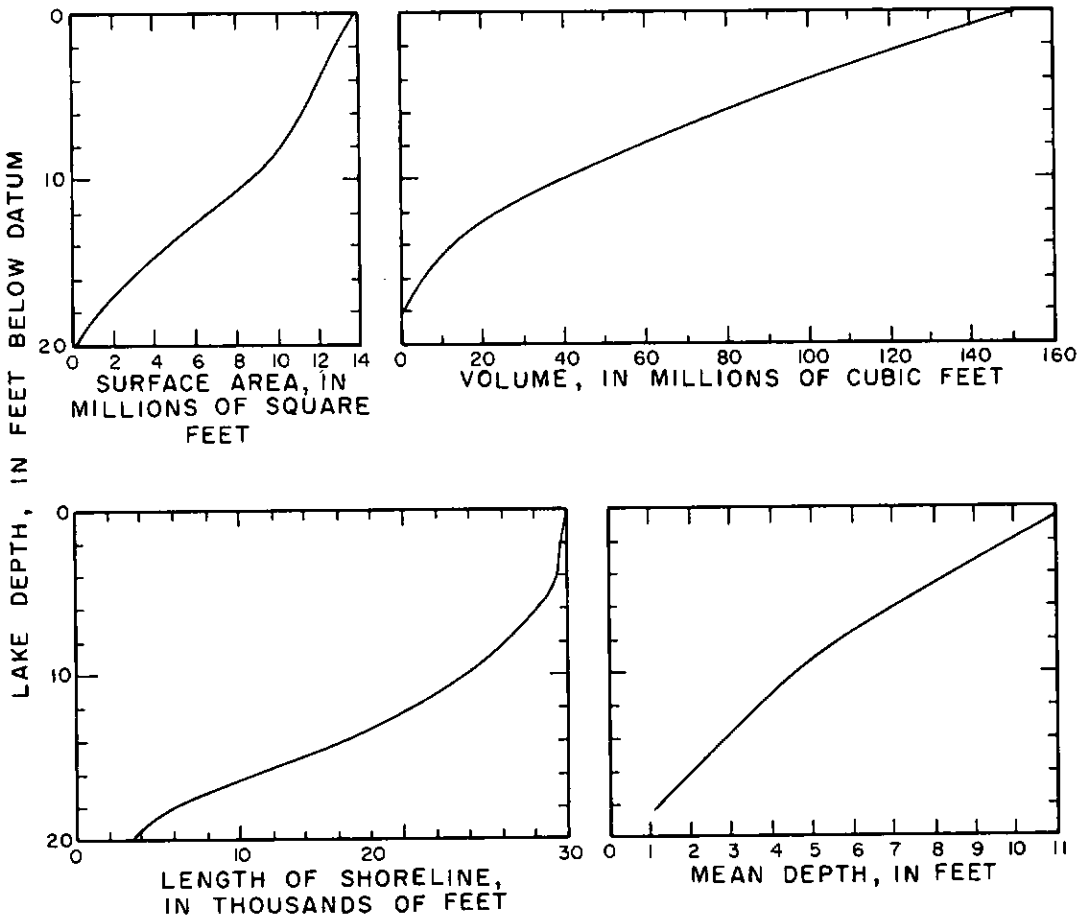
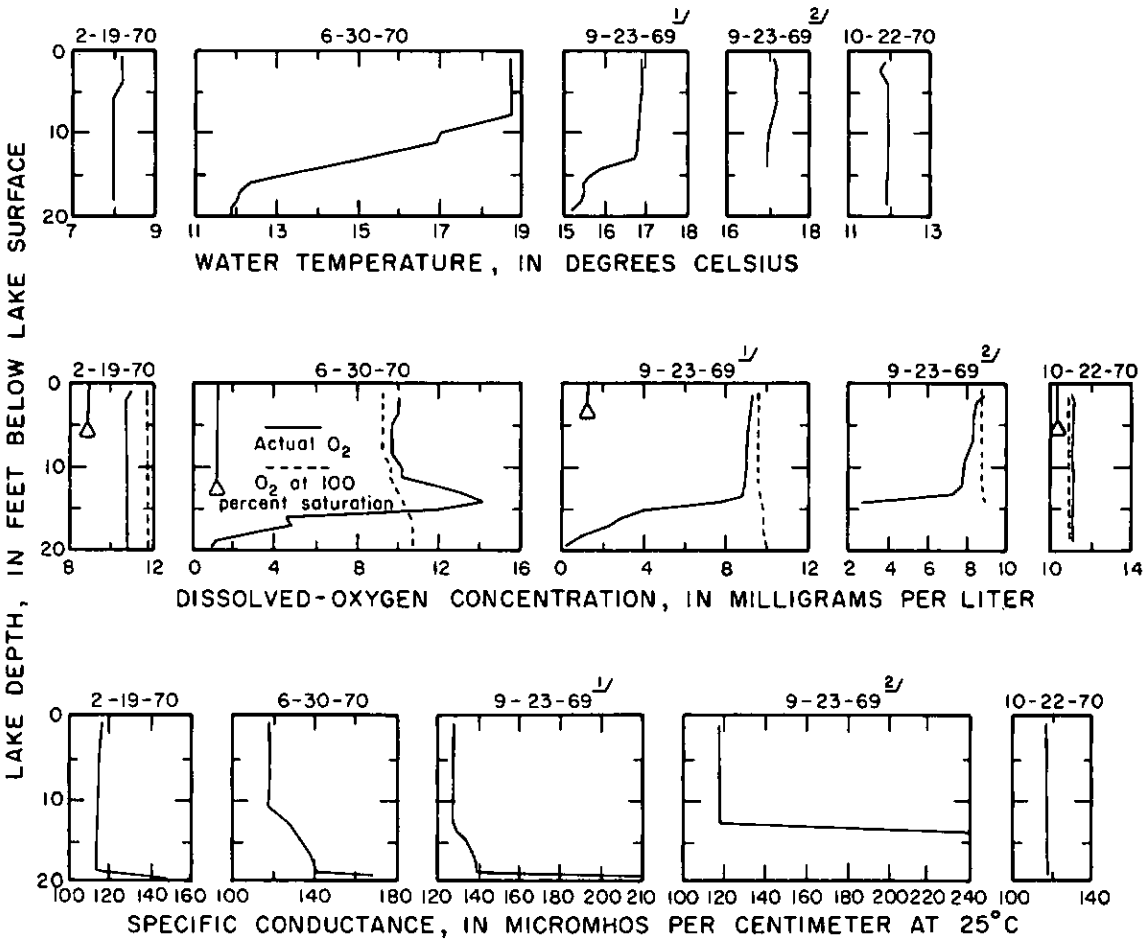


FIGURE 58. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Steilacoom Lake near Steilacoom. Zero-depth datum is 210 feet above mean sea level, based on topographic-map altitude.

Figure 58 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 59 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.



1/ Sampled in south end of lake.

2/ Sampled in north end of lake, at depth of 14 feet.

FIGURE 59. – Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Steilacoom Lake near Steilacoom, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. Except as noted, all profiles taken in deepest part of lake. DO profile for June 30 shows positive heterograde development, with a 140-percent oxygen saturation at 14 ft.

Lake stages.--Regulated by flashboards in weir, from April 1 to October 31 of each year.

Observations of lake stage, obtained from staff gage on the bridge spanning center of lake, were:

Date	Lake stage (in ft above msl)
9-23-69	209.17
2-19-70	209.70
5-11-70	209.51
6-30-70	209.53
10-23-70	209.13
11-10-70	208.47

Surface-water inflow and outflow.--Major inflow is from Ponce de Leon Creek on southeast end of lake and Clover Creek on south end of lake, while outflow is via Chambers Creek on north end of lake. The maximum and minimum outflow discharges at recording gage on Chambers Creek (12091040. Chambers Creek above Flett Creek) since 1965 were 271 cfs and 17 cfs, respectively. The maximum flow occurred in January and the minimum flow was in September.

Miscellaneous measurements of surface-water inflow are listed below:

Date	Inflow (in cfs)
2-19-70	141
6-30-70	10.2
10-22-70	7.78

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	2-19-70	10-22-70
Depth of samples below surface, in ft	10	[a]3,10, and 17
Silica (SiO_2)	12	15
Iron (Fe)	--	.02
Manganese (Mn)	--	.00
Calcium (Ca)	11	--
Magnesium (Mg)	3.4	--
Sodium (Na)	5.3	--
Potassium (K)	1.1	--
Bicarbonate (HCO_3)	43	61
Carbonate (CO_3)	0	0
Sulfate (SO_4)	7.6	8.3
Chloride (Cl)	5.6	5.1
Fluoride (F)	.1	.1
Dissolved solids (residue at 180°C)	74	89
Hardness Ca-Mg	42	--
Hardness Noncarbonate	7	--
Alkalinity	35	50
pH, units	6.8	7.7
Color, Co-Pt units	10	0

[a]Averages for three samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 59.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-23-69	1	0.000	0.000	0.02	--	--	--	0.16
2-19-70	10	.000	.006	.90	--	--	--	.93
6-30-70	17	.010	.036	.50	--	--	--	.54
10-22-70	3	.049	.055	.20	0.000	0.05	0.03	.28
10-22-70	10	.052	.059	.20	.000	.03	.02	.25
10-22-70	17	.049	.052	.04	.000	.03	.02	.05

Macrophytes.--Area of macrophytes 0.01 percent of lake area, October 22, 1970.

Aquatic plants in the lake were scarce, however, small patches of the following were found: pondweed (Potamogeton), waterweed (Elodea), water nymph (Najas), and sedge (Cyperus). The water nymph was found washed ashore, possibly from the deeper water.

Remarks.--North end of lake has many submerged tree stumps. In many places riparian vegetation extends across the littoral zone.

Conclusions.--Steilacoom Lake has a very shallow mean depth relative to its surface area--relative depth is 0.5 percent. Also, the lake is in an urban environment. Because of its environment and shape, the lake is subject to fecundation and is biologically very productive, as shown by high concentrations of dissolved solids and total nitrogen and

by the summer development of oxygen maxima (caused by photosynthesis) in the metalimnion and an oxygen deficit in the hypolimnion of the summer dissolved-oxygen profile. The lake is treated with algacides and herbicides to control some types of aquatic flora and fauna and therefore, only a small percentage of the lake surface was found to have observable macrophytes.

12093505. Forest Lake near Orting

Location.--Southernmost tip of lake at lat 47°02'54", long 122°11'29"; lake occupies part of NE¼ sec. 17, T.18 N., R.5 E., Pierce County.

Origin.--Kettle lake.

Basin geology.--Kame-and-kettle topography composed mainly of glacial outwash.

Soils.--Rolling, hilly and rough broken land covered with sandy gravelly loam and gravelly sandy loam.

Land use and cover.--Commercial forest land.

A picnicking area is the only development on the lake. Outdoor toilet facilities are about 200 ft from the water's edge.

Vegetal cover on the lakeshore is mainly deciduous trees (alder, dogwood, and maple) and cedar. The rest of the basin is mainly fir, cedar and hemlock. Underbrush is predominantly swordfern. South of the lake is a swamp area supporting bulrush, sedge, grasses, skunk cabbage, and peat.

Population.--No lakeshore dwellings as of October 1970.

However, there is summer use of a picnicking area. In the lake basin there is one residence.

Physical features of lake.--Bathymetric map shown in figure 60 (Wolcott, 1965, p. 316).

Some morphometric parameters, at a lake stage of 520 ft (msl), are:

Drainage area-------- 0.46 sq mi	Length of shoreline- 2,520 ft
Altitude of deepest part of lake (using msl datum)---------- 482 ft	Length of lake-------- 965 ft
	Breadth of lake------- 610 ft
	Shoreline configuration- 1.37
Surface area------ 270,000 sq ft	Development of volume--- 0.36
Lake volume-- 3.34 million cu ft	Relative depth---- 5.8 percent
Mean depth---------- 12.4 ft	Mean slope---------- 8°50'
Maximum depth---------- 38 ft	

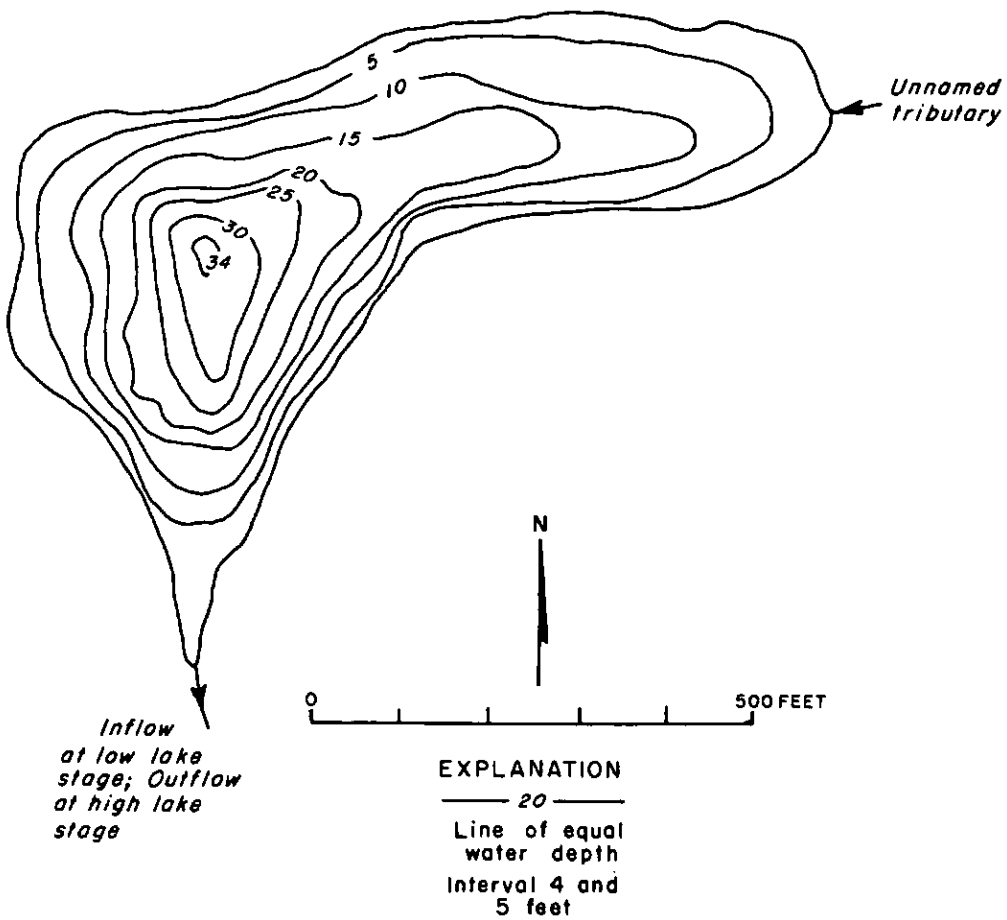


FIGURE 60. – Forest Lake near Orting, surveyed August 17, 1947 by State Department of Game (map from Wolcott, 1965, p. 316). Zero-depth datum is 520 ft. (msl).

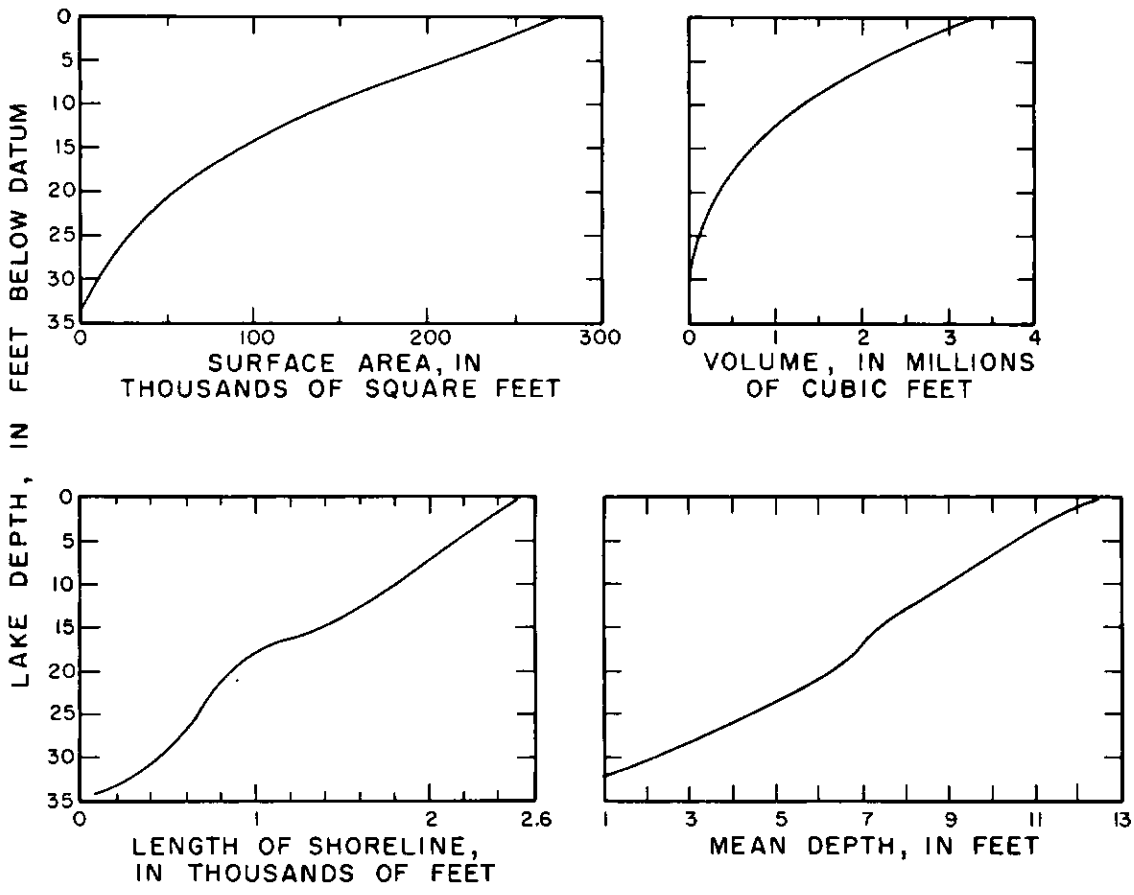


FIGURE 61. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Forest Lake near Orting. Zero-depth datum is 520 feet above mean sea level, based on topographic-map altitude.

Figure 61 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 62 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-12-69	530.16
2-12-70	531.49
6-29-70	532.16
10- 9-70	529.83

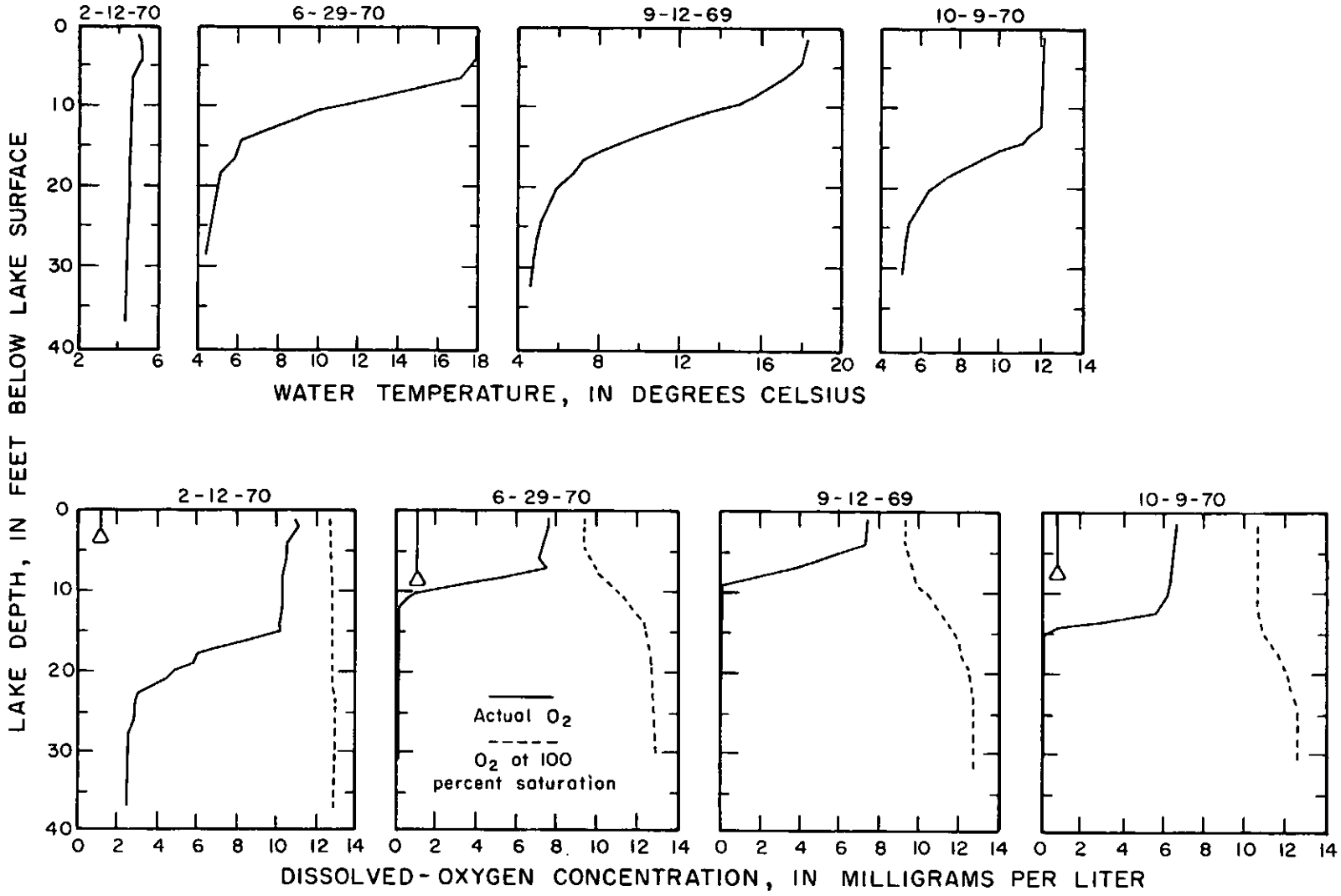


FIGURE 62. – Selected seasonal profiles of lake temperature and DO concentration, Forest Lake near Orting, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profile.

Surface-water inflow and outflow.--Closed basin, fed by springs.

During high stages the lake spills into the swamp in the southwestern part of the basin and returns at lower stages. Measurements of visible surface-water spring inflow are:

Date	Inflow (in cfs)
2-12-70	0.3
6-29-70	.1
10- 9-70	.15

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-12-70	10-9-70	10-9-70
Depth of samples below surface, in ft	14	[a]3 and 13	27
Silica (SiO_2)	14	12	16
Iron (Fe)	--	.08	1.9
Manganese (Mn)	--	.01	.19
Calcium (Ca)	6.4	6.6	7.3
Magnesium (Mg)	3.1	3.4	3.3
Sodium (Na)	3.6	3.8	3.5
Potassium (K)	1.3	1.4	1.4
Bicarbonate (HCO_3)	39	45	47
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	.2	--	.4
Chloride (Cl)	2.5	2.2	2.1
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	62	74	81
Hardness Ca-Mg	29	30	32
Hardness Noncarbonate	0	0	0
Alkalinity	32	37	39
pH, units	7.0	7.0	6.6
Color, Co-Pt units	30	20	50

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 63.

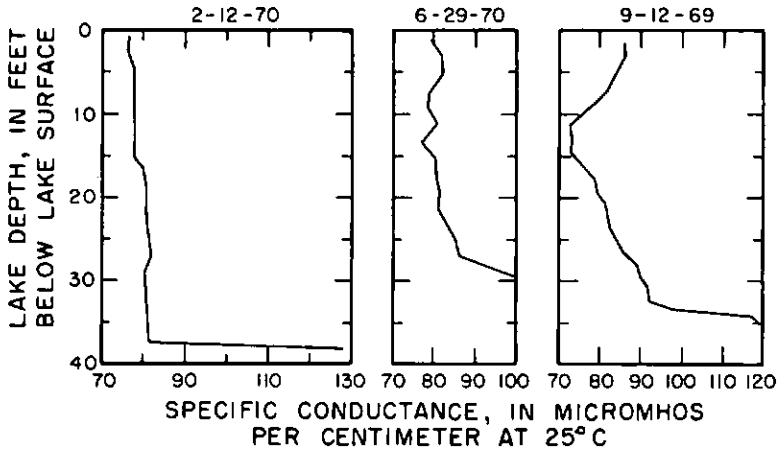


FIGURE 63. – Selected profiles of specific conductance, Forest Lake near Orting, 1969-70.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-12-69	1	0.006	0.023	0.07	--	--	--	0.34
2-12-70	14	.006	.052	.10	--	--	--	.43
6-29-70	29	.003	.003	.09	--	--	--	.29
10- 9-70	3	.016	.016	.20	0.015	0.10	0.14	.46
10- 9-70	13	.016	.016	.07	.009	.09	.09	.29
10- 9-70	27	.049	.049	.20	.000	.32	.01	.53

Macrophytes.--Few aquatic plants found during the October survey. However, the few plants found were waterlily (Nuphar) and a broad-leaved Potamogeton, probably bassweed.

Remarks.--Littoral zone covered with fallen logs and rotting organic debris.

Conclusions.--Forest Lake is in an almost totally natural environment and is rich in nutrients from mostly natural sources. The color and specific conductance are fairly high, and the transparency is fairly shallow. The lake has hypolimnetic-oxygen deficits in both summer and winter, indicating that mixing during the winter is incomplete, probably because of the lake's shape--the development of volume is 0.36, almost that of a cone, while the relative depth of 5.8 percent is among the highest of all the lakes studied.

12110002. Wilderness Lake near Maple Valley

Location.--Surface-water outlet at lat 47°22'04", long 122°02'12"; lake in SE¼ sec.21, SW¼ sec.22, and NW¼ sec.27, T.22 N., R.6 E., King County.

Origin.--Kettle lake.

Basin geology.--Glacial till and outwash.

Soils.--Shallow and moderately deep, gravelly loamy sand and sandy loam soils.

Land use and cover.--Two-thirds residential, includes resort and park.

The remainder of basin covered by moderate stand of second-growth evergreen and deciduous trees.

Population.--House count of October 1970 noted 44 dwellings, as compared to 40 lakeshore residences in 1968 (estimated from U.S. Geological Survey topographic map). Only seven of present dwellings appeared to be seasonal residences. Most of the development is on the south and west sides of the lake.

Physical features of lake.--Bathymetric map shown in figure 64 (Wolcott, 1965, p. 106).

Some morphometric parameters at a lake stage of 470 ft (msl), are:

Drainage area	0.66 sq mi	Length of shoreline	9,400 ft
Altitude of deepest part of lake (using msl datum)	432 ft	Length of lake	3,480 ft
		Breadth of lake	1,400 ft
Surface area	3.00 million sq ft	Shoreline configuration	1.53
Lake volume	62.0 million cu ft	Development of volume	0.54
Mean depth	20.8 ft	Relative depth	1.9 percent
Maximum depth	38 ft	Mean slope	4°24'

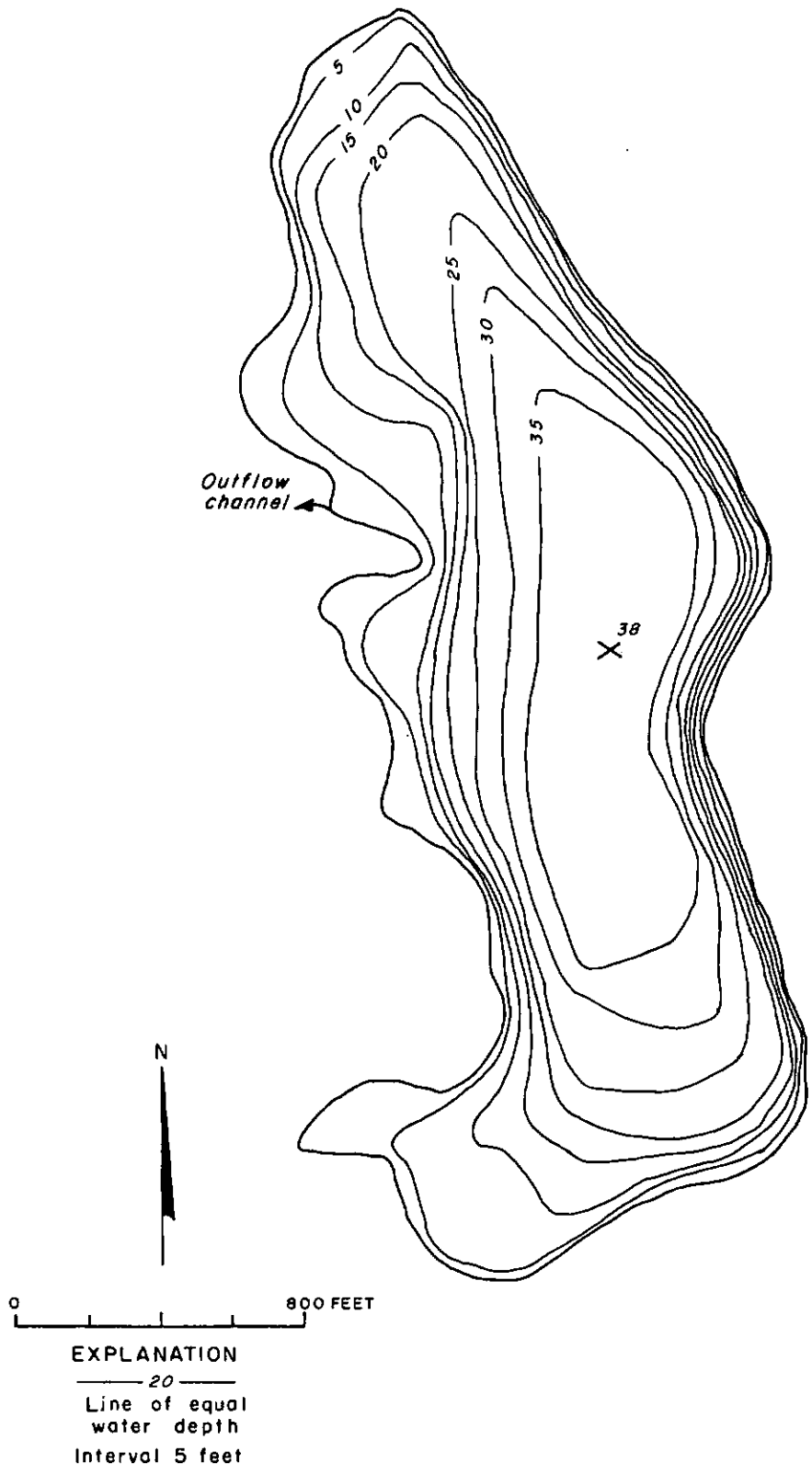


FIGURE 64. – Wilderness Lake near Maple Valley, surveyed July 25, 1952 by State Department of Game (map from Wolcott, 1965, p. 106). Zero-depth datum is 470 ft. (msl).

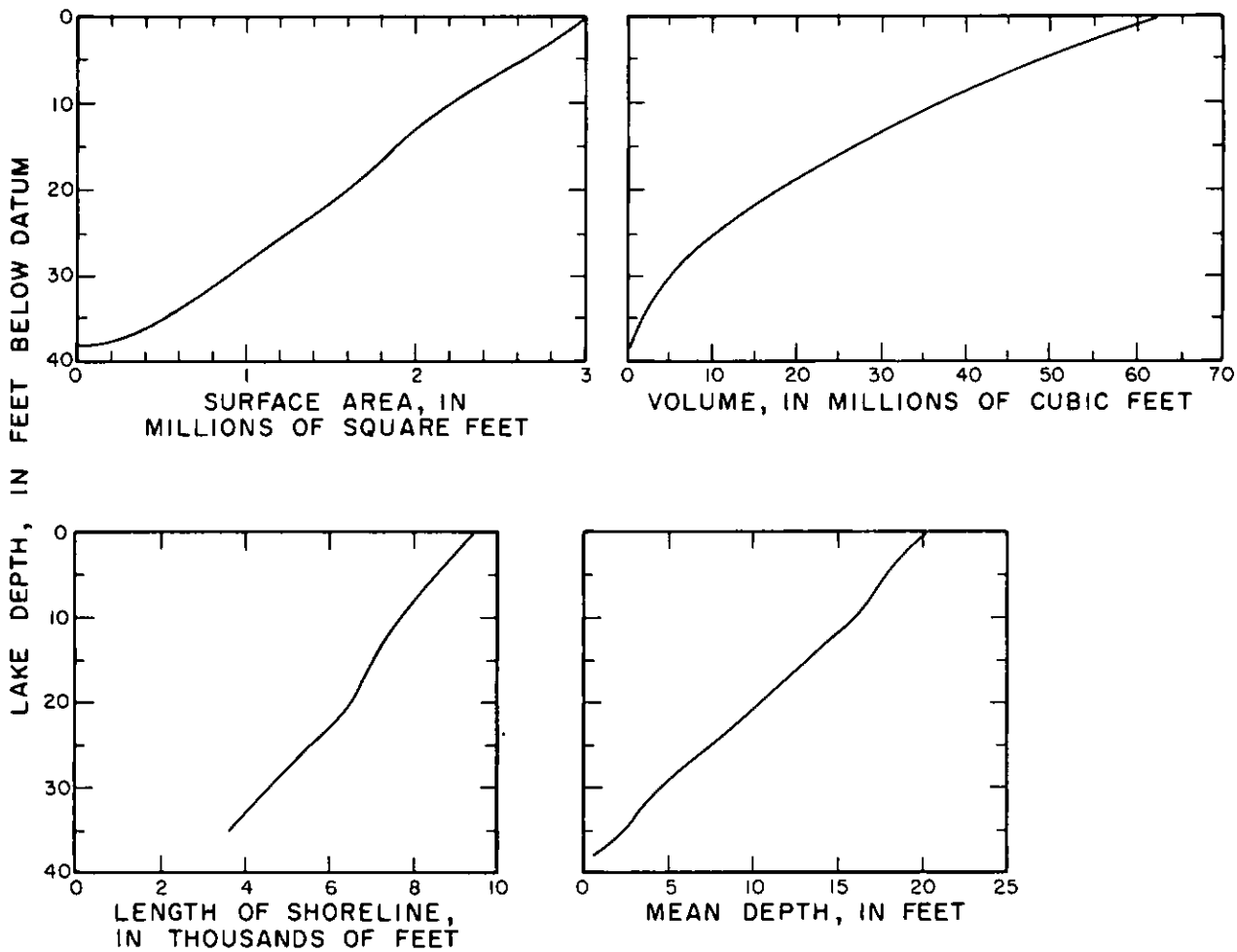


FIGURE 65. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Wilderness Lake near Maple Valley. Zero-depth datum is 470 feet above mean sea level, based on topographic-map altitude.

Figure 65 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 66 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

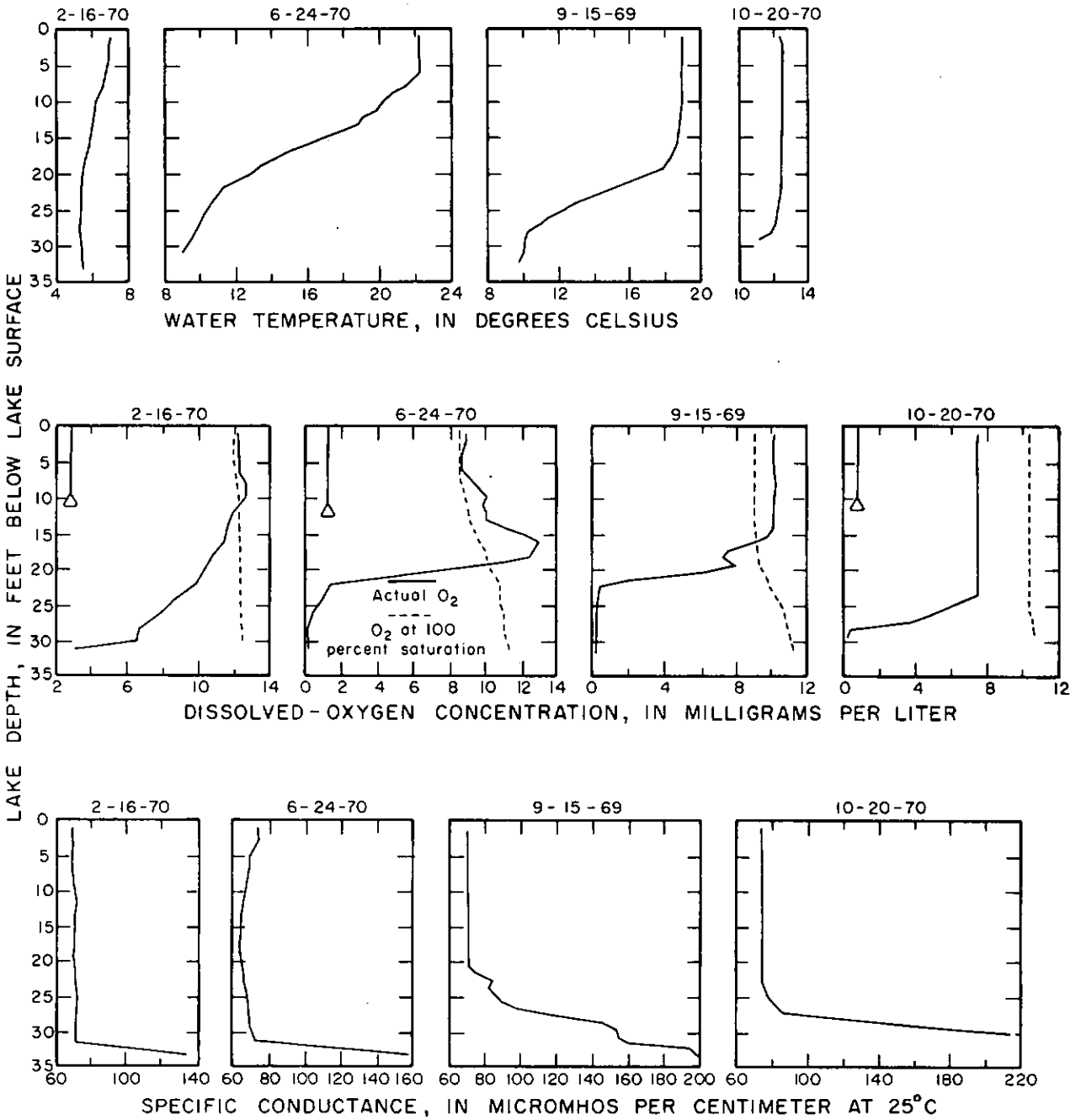


FIGURE 66. – Selected profiles of lake temperature, DO concentration, and specific conductance, Wilderness Lake near Maple Valley, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. Note the excellent development of a positive heterograde on the DO profile for June 24, showing a 133-percent oxygen saturation at 16 ft.

Lake stages.--Regulation of outflow for irrigation during summer months.

Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-15-69	469.88
2-16-70	470.51
6-24-70	469.97
10-20-70	469.41

Surface-water inflow and outflow.--No visible inflow.

A small intermittent outflow channel exists on the west shore of the lake. Miscellaneous measurements of outflow are listed below.

Date	Outflow (in cfs)
9-15-69	0.01
2-16-70	4.40
6-24-70	.83
10-20-70	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-16-70	10-20-70	10-20-70
Depth of samples below surface, in ft	18	[a]3 and 24	28
Silica (SiO_2)	10	9.7	9.6
Iron (Fe)	--	.12	.32
Manganese (Mn)	--	.03	.07
Calcium (Ca)	8.0	--	--
Magnesium (Mg)	1.8	--	--
Sodium (Na)	2.8	--	--
Potassium (K)	.4	--	--
Bicarbonate (HCO_3)	32	38	39
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	6.0	3.1	3.4
Chloride (Cl)	2.3	1.9	1.9
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	50	52	53
Hardness Ca-Mg	28	--	--
Hardness Noncarbonate	2	--	--
Alkalinity	26	31	32
pH, units	6.7	7.1	7.0
Color, Co-Pt units	5	5	5

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 66.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-15-69	1	0.003	0.016	0.00	--	--	--	0.11
2-16-70	18	.003	.020	.20	--	--	--	.18
6-24-70	36	.003	.055	.09	--	--	--	.34
10-20-70	3	.020	.033	.30	0.085	0.11	0.06	.55
10-20-70	24	.026	.033	.20	.000	.00	.04	.24
10-20-70	28	.042	.049	.30	.180	.01	.02	.51

Macrophytes.--Area of macrophytes 0.4 percent of lake area, October 20, 1970.

The dominant macrophytes found were waterweed (Elodea), pondweed (Potamogeton), waterlily (Nuphar), and cattail (Typha).

Remarks.--October 1970, algal bloom noted on south and west edges of lake.

Conclusions.--The biologic productivity and trophic nature of Wilderness Lake is considered to be medium to high, as evidenced by the abundance of macrophytes and algal blooms, moderate winter nutrient content, fairly high specific-conductance concentrations, the summer development of a zone of oxygen supersaturation in the metalimnion and oxygen depletion in the hypolimnion of the summer dissolved-oxygen profile. The flushing rate of the lake is probably slow and, even though only part of the lakeshore is occupied by dwellings, increased fecundation, nutrient buildup, and an increased rate of eutrophication would be quite easily accomplished.

12110004. Pipe Lake near Maple Valley

Location.--Surface-water outlet (channel connected to Lucerne Lake) at lat 47°21'58", long 122°03'06"; lake in secs. 28 and 29, T.22 N., R.6 E., King County.

Origin.--Kettle lake.

Basin geology.--Glacial till.

Soils.--Rolling gravelly sandy loam.

Land use and cover.--Mainly residential with moderate growth of evergreens.

Population.--House count of October 1970 noted church camp, country club, recreation area, and 42 permanent and 22 seasonal dwellings (totaling 64 dwellings) on lakeshore as compared to seven dwellings in 1934 (State of Washington Dept. of Game field notes), and about 40 dwellings in 1949 (estimated from U.S. Geological Survey topographic map).

Physical features of lake.--Bathymetric map shown in figure 67 (Wolcott, 1965, p. 108).

Some morphometric parameters, at a lake stage of 530 ft (msl), are:

Drainage area	0.63 sq mi	Length of shoreline	9,000 ft
Altitude of deepest part of lake (using msl datum)	465 ft	Length of lake	2,560 ft
		Breadth of lake	1,150 ft
Surface area	2.39 million sq ft	Shoreline configuration	1.64
Lake volume	63.4 million cu ft	Development of volume	0.41
Mean depth	26.5 ft	Relative depth	3.7 percent
Maximum depth	65 ft	Mean slope	7°28'

Figure 68 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 69 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

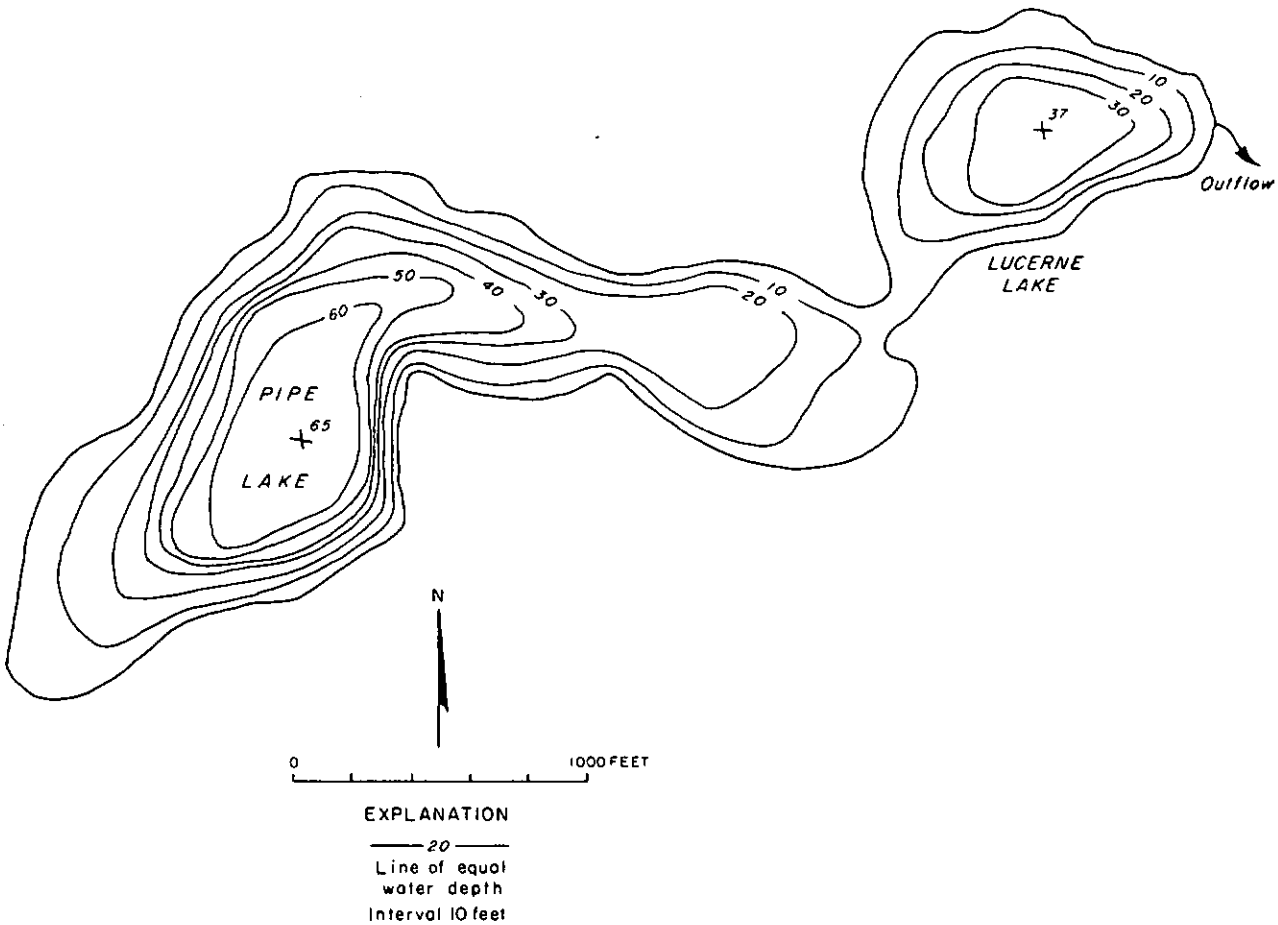


FIGURE 67. – Pipe Lake near Maple Valley and Lucerne Lake near Maple Valley, surveyed February 3, 1955 by State Department of Game (map from Wolcott, 1965, p. 108). Zero-depth datum is 530 ft. (msl).

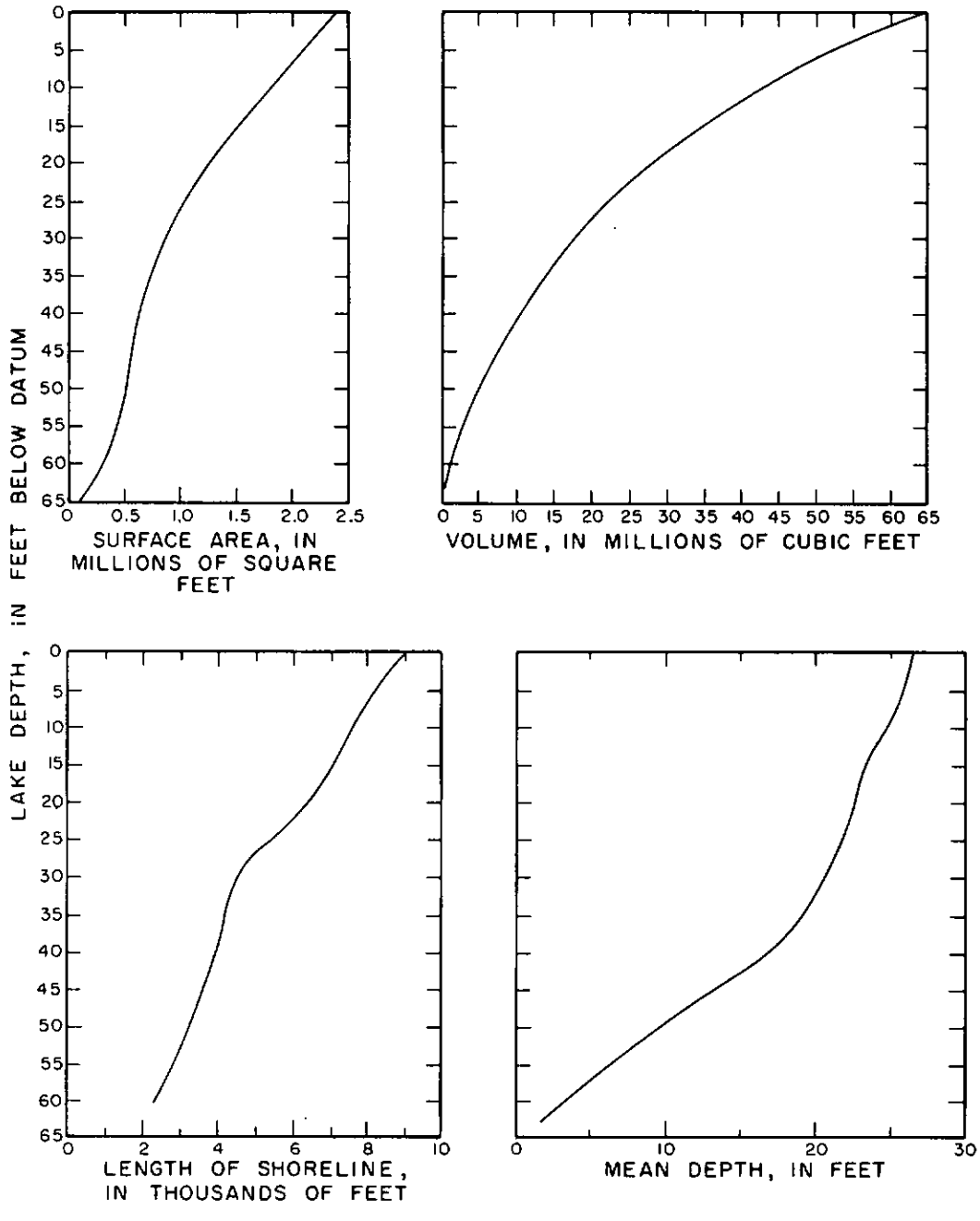


FIGURE 68. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Pipe Lake near Maple Valley. Zero-depth datum is 530 feet above mean sea level, based on topographic-map altitude.

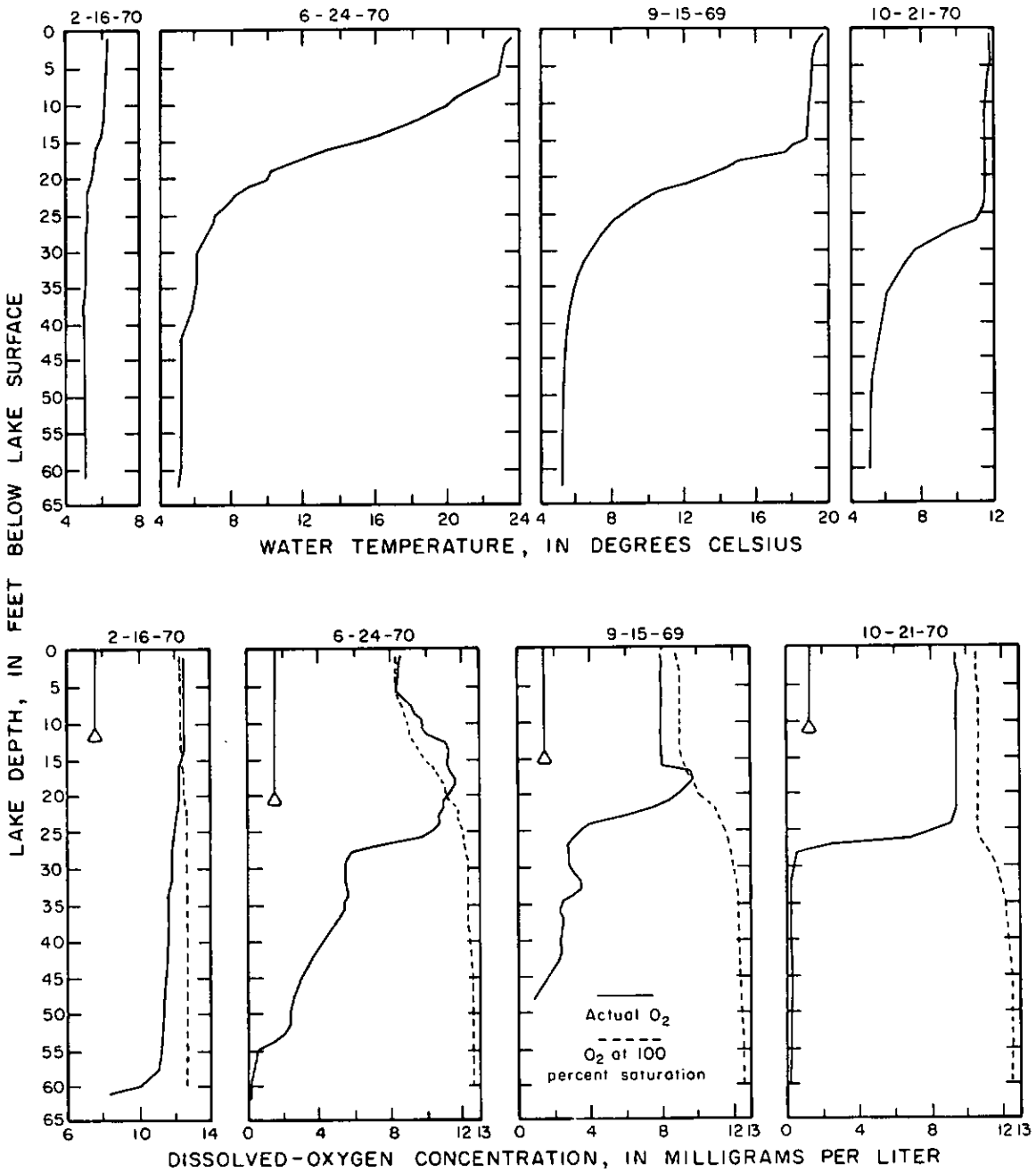


FIGURE 69. – Selected profiles of lake temperature and DO concentration, Pipe Lake near Maple Valley, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. DO profile for June 24 shows a positive heterograde development, with 109-percent oxygen saturation at 18 ft.

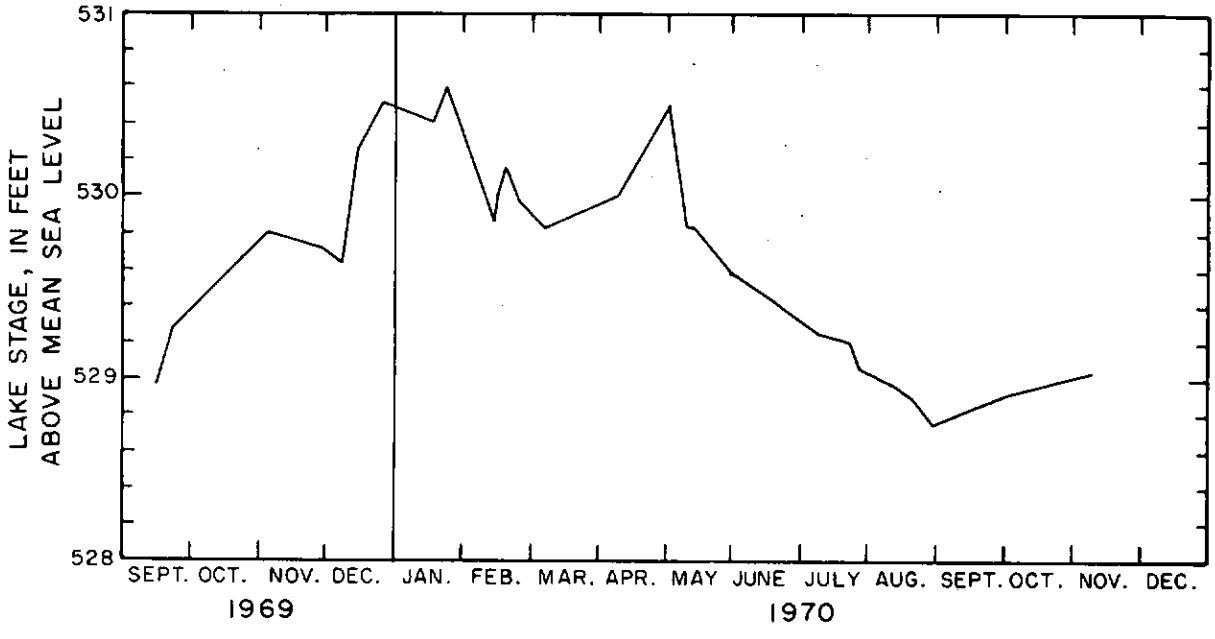


FIGURE 70. – Observed lake stages of Pipe Lake near Maple Valley and Lucerne Lake near Maple Valley.

Lake stages.--Original lake level was raised, sometime prior to 1934, by road fill across outlet of Lucerne Lake (Lucerne and Pipe Lakes are connected).

A hydrograph of lake stages is shown in figure 70.

Surface-water inflow and outflow.--Surface-water inflow, from precipitation, local storm runoff, and springs.

Surface-water outflow is through Lucerne Lake via an 80-ft wide, 10-ft deep channel connecting the two lakes. (See p.156 for outflow measurements of Lucerne Lake.)

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-16-70	10-21-70	10-21-70
Depth of samples below surface, in ft	30	[a]3 and 26	55
Silica (SiO_2)	3.7	2.3	4.9
Iron (Fe)	--	.02	1.8
Manganese (Mn)	--	.01	.38
Calcium (Ca)	4.6	--	--
Magnesium (Mg)	1.3	--	--
Sodium (Na)	3.0	--	--
Potassium (K)	.4	--	--
Bicarbonate (HCO_3)	19	20	26
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	5.0	3.2	4.1
Chloride (Cl)	2.8	2.5	2.3
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	37	36	45
Hardness Ca-Mg	17	--	--
Hardness Noncarbonate	2	--	--
Alkalinity	16	16	21
pH, units	6.5	7.1	6.5
Color, Co-Pt units	20	5	30

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 71.

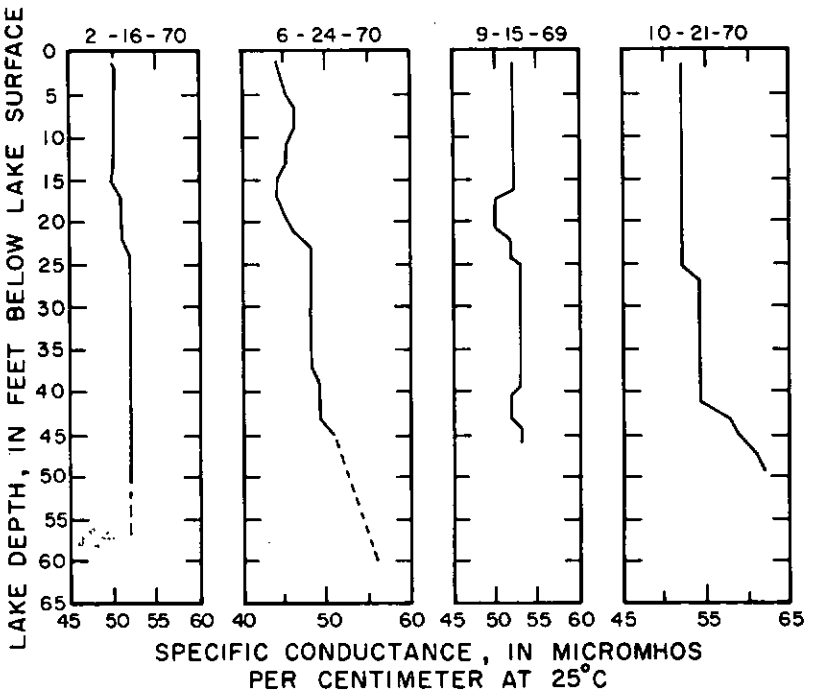


FIGURE 71. – Selected seasonal profiles of specific conductance, Pipe Lake near Maple Valley, 1969-70.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-15-69	1	0.003	0.010	0.00	--	--	--	0.14
2-16-70	30	.000	.013	.07	--	--	--	.11
6-24-70	59	.000	.006	.20	--	--	--	.29
10-21-70	3	.006	.013	.07	0.000	0.05	0.02	.17
10-21-70	26	.006	.010	.10	.000	.07	.02	.19
10-21-70	55	.023	.033	.20	.150	.39	.15	.89

Macrophytes.--Area of macrophytes 1.9 percent of lake area, October 21, 1970.

Waterlily (Nuphar) was the dominant emergent plant. Other aquatics found, but less abundant, were cattail (Typha), waterweed (Elodea), pondweed (Potamogeton), and unidentified varieties of grass. In 1934, sedge, Potamogeton, sponges and Chara [muskgrass?] were noted in the lake, none were overly abundant (State of Washington Dept. of Game field notes); however, no waterlilies, the dominant plant now, were noted.

Conclusions.--Pipe Lake has about medium biologic productivity at present, as shown by the moderate winter nutrient content, the metalimnetic oxygen-supersaturation zone and oxygen depletion in the hypolimnion of the summer dissolved-oxygen profile. The sources of lake enrichment are both natural and cultural. However, cultural enrichment is increasing because development around the lake has been almost tenfold in the past 36 years. An increased abundance and number of genera of macrophytes have been noted in the lake. Individual lake residents are attempting to eradicate aquatic weeds.

12110005. Lucerne Lake near Maple Valley

Location.--Surface-water outlet at lat 47°22'05", long 122°02'05"; lake in sec. 28, T.22 N., R.6 E., King County.

Origin.--Kettle lake.

Basin geology.--Glacial till.

Soils.--Rolling gravelly sandy loam soils.

Land use and cover.--Mainly residential with moderate growth of evergreen and deciduous trees.

Most lakeshore homes have lawns which extend to the water's edge.

Population.--House count of October 1970 noted 25 permanent and 19 summer dwellings (totaling 44 dwellings) encircling the lake, as compared to 10 dwellings in 1934 (State of Washington Dept. of Game field notes), and 30 dwellings in 1949 (estimated from U.S. Geological Survey topographic map).

Physical features of lake.--Littoral zone predominantely gravel with local areas of muck and sand.

Bathymetric map is shown in figure 67 on page 146 (Wolcott, 1965, p. 108).

Some morphometric parameters, at a lake stage of 530 ft (msl), are:

Drainage area	0.63 sq mi	Length of shoreline	3,670 ft
Altitude of deepest part of lake (using msl datum)	493 ft	Length of lake	1,350 ft
		Breadth of lake	830 ft
Surface area	783,000 sq ft	Shoreline configuration	1.17
Lake volume	13.7 million cu ft	Development of volume	0.47
Mean depth	17.5 ft	Relative depth	3.7 percent
Maximum depth	37 ft	Mean slope	5°33'

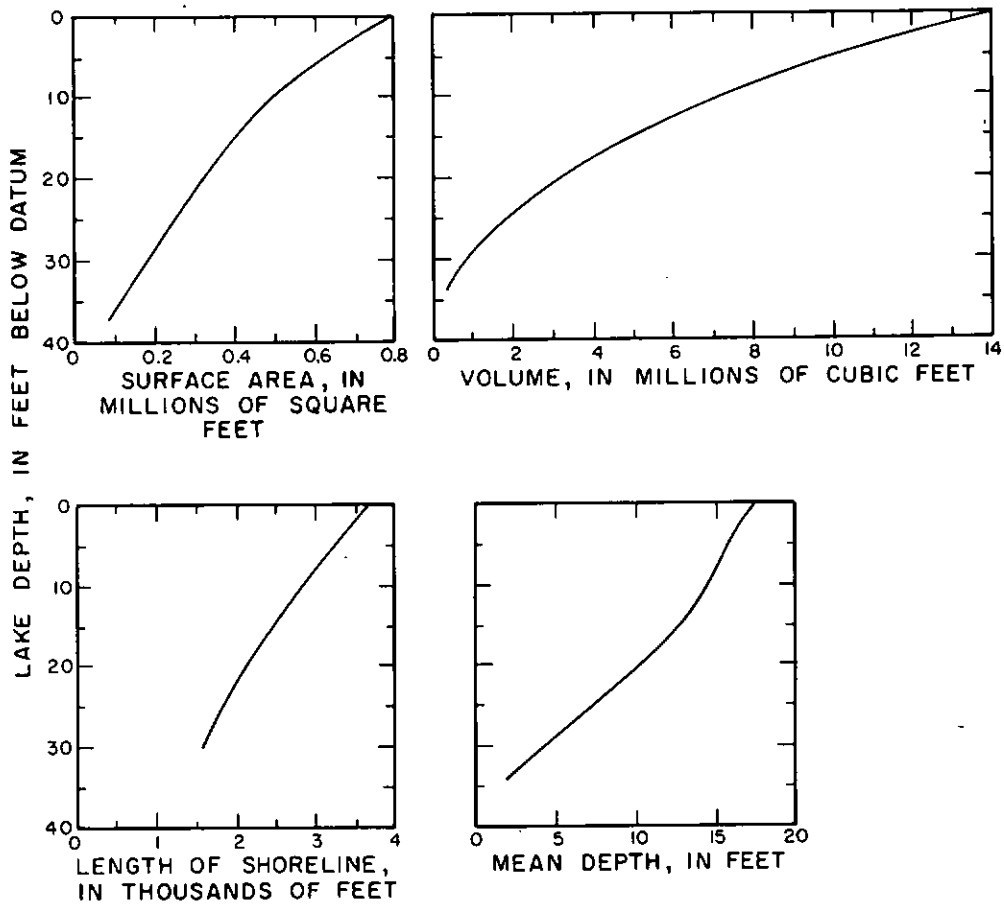


FIGURE 72. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Lucerne Lake near Maple Valley. Zero-depth datum is 530 feet above mean sea level, based on topographic-map altitude.

Figure 72 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 73 shows profiles of DO concentration, specific conductance, and water temperature, as well as Secchi-disc transparency depths.

Lake stages.--From staff gage located in Pipe Lake.

A hydrograph of observed lake stages is shown in figure 70.

Surface-water inflow and outflow.--Aside from essentially nonflowing connection with Pipe Lake, via an 80-ft wide 10-ft deep channel, lake has only intermittent springs for inflow. Outflow is through a culvert on the east end of the lake.

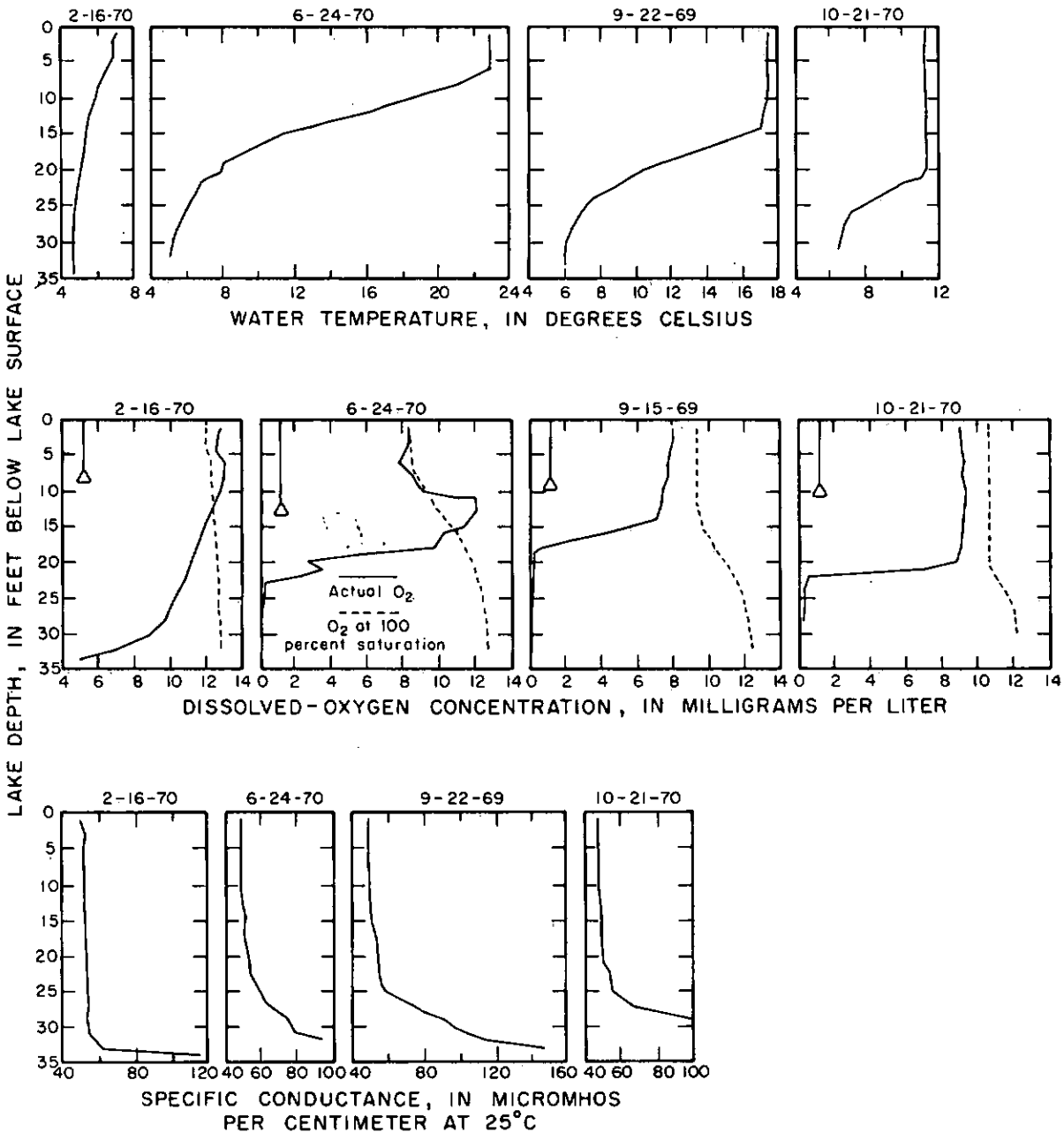


FIGURE 73. – Selected seasonal profiles of lake temperature, DO concentration, and specific conductance, Lucerne Lake near Maple Valley, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. DO profile for June 24 shows a positive heterograde development with 125-percent oxygen saturation at 11 ft.

Miscellaneous measurements are:

Date	Inflow (in cfs)	Outflow (in cfs)
9-15-69	0	0
9-22-69	0	0
2-16-70	0	1.97
6-24-70	0	0
10-21-70	0	0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	2-16-70	10-21-70	10-21-70
Depth of samples below surface, in ft	16	[a] 3 and 22	27
Silica (SiO_2)	3.6	2.2	4.7
Iron (Fe)	--	.04	.55
Manganese (Mn)	--	.01	.37
Calcium (Ca)	4.6	--	--
Magnesium (Mg)	1.3	--	--
Sodium (Na)	3.1	--	--
Potassium (K)	.4	--	--
Bicarbonate (HCO_3)	19	20	24
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	5.0	2.7	3.2
Chloride (Cl)	2.7	3.0	2.6
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	54	36	38
Hardness Ca-Mg	17	--	--
Hardness Noncarbonate	2	--	--
Alkalinity	16	16	20
pH, units	6.5	6.9	6.4
Color, Co-Pt units	10	5	5

[a] Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 73.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-22-69	1	0.000	0.000	0.00	--	--	--	0.01
2-16-70	16	.026	.026	.10	--	--	--	.14
6-24-70	30	.003	.026	.09	--	--	--	.38
10-21-70	3	.003	.006	.10	0.000	0.03	0.01	.14
10-21-70	22	.006	.006	.09	.010	.05	.02	.18
10-21-70	27	.006	.010	.50	.000	.53	.21	1.20

Macrophytes.--Area of macrophytes 5.1 percent of lake area, October 21, 1970.

Waterlily (Nuphar) was the dominant macrophyte found; pondweed (Potamogeton) and waterweed (Elodea) were found in lesser quantities. In 1934, sedges, pondweed, sponges, and Chara were noted (State of Washington Dept. of Game field notes); however, no waterlilies, the dominant macrophyte now, were reported.

Conclusions.--Lucerne Lake has medium to high biologic productivity. The prolific nature and trophic condition of the lake is shown by a high surface coverage of macrophytes, moderate to high winter-nutrient and dissolved-solids content, hypolimnetic-oxygen depletion in summer and the formation of a metalimnetic oxygen-supersaturated zone in the summer dissolved-oxygen profile. Because the lake has a comparatively low ratio of volume of water per dwelling, increased rates of fecundation may cause critical increases in eutrophication.

12142295. Hancock Lake near Snoqualmie

Location.--Surface-water outlet at lat 47°34'21", long 121°41'12"; lake in secs. 8,9,16, and 17, T.24 N., R.9 E., King County.

Origin.--Glaciated valley dammed by moraine deposits.

Basin geology.--Sedimentary and volcanic rocks, predominately sedimentary with granitic rocks in the upper end of basin.

Soils.--Gravelly loam soils on steeply sloping uplands.

Land use and cover.--Covered by conifer forest.

On the west tip of the lake basin the timber is being harvested. The logged area accounts for less than 0.05 percent of the total drainage to the lake.

Population.--House count of October 1970 noted 22 summer-occupied cabins with outdoor facilities on north shore of lake; remainder of basin unpopulated.

Physical features of lake.--Littoral zone is sand and silt at north end and gravel and boulders in matrix of silt and sand at south end.

Bathymetric map shown in figure 74 (Wolcott, 1965, p. 143).

Some morphometric parameters, at a lake stage of 2,167 ft (msl), are:

Drainage area	7.67 sq mi	Length of shoreline	14,500 ft
Altitude of deepest part of lake (using msl datum)	2,131 ft	Length of lake	5,690 ft
Surface area	10.7 million sq ft	Breadth of lake	2,460 ft
Lake volume	272 million cu ft	Shoreline configuration	1.25
Mean depth	25.4 ft	Development of volume	0.70
Maximum depth	36 ft	Relative depth	0.97 percent
		Mean slope	1°24'

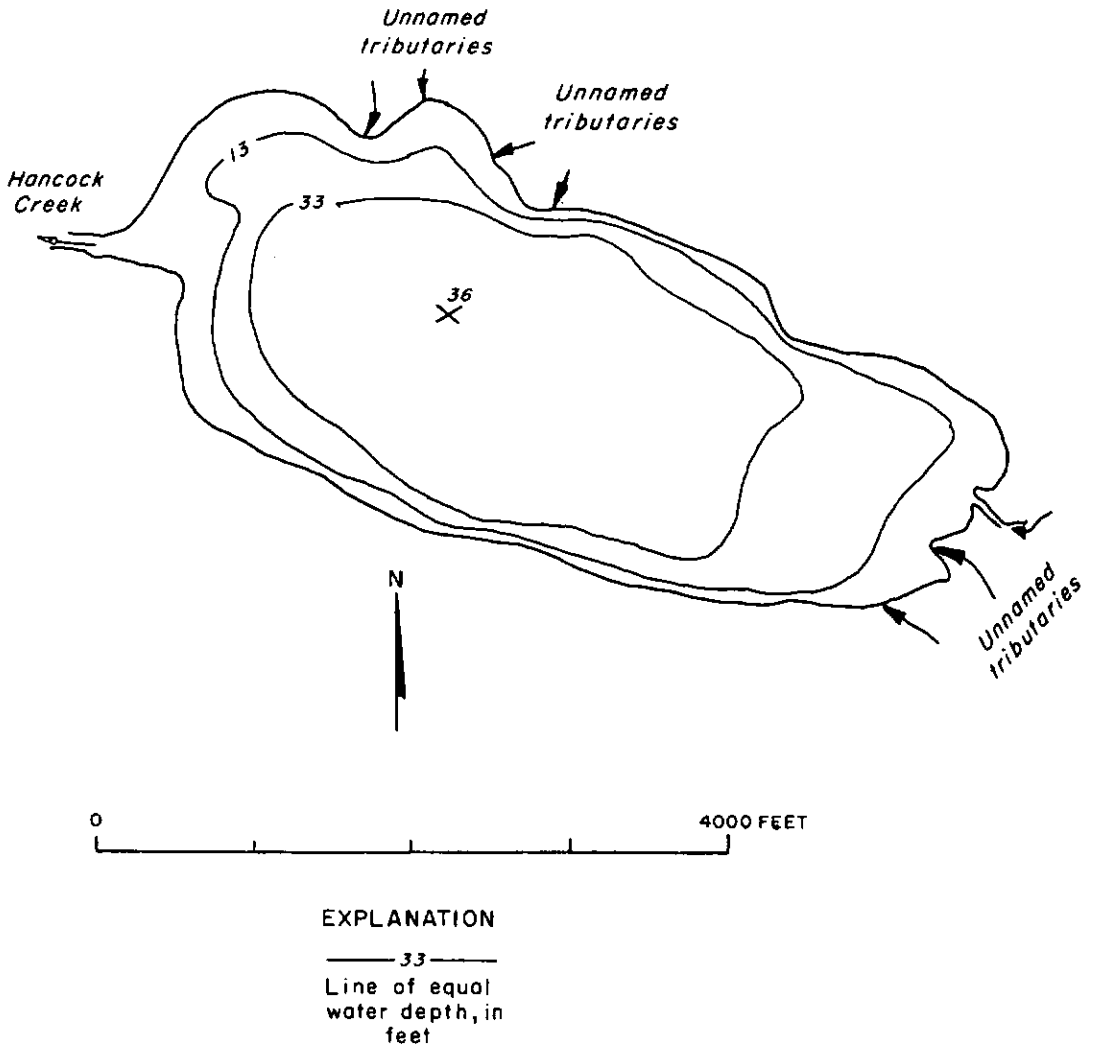


FIGURE 74. – Hancock Lake near Snoqualmie, surveyed October 7, 1953 by U.S. Geological Survey (map from Wolcott, 1965, p. 143). Zero-depth datum is 2,167 ft. (msl).

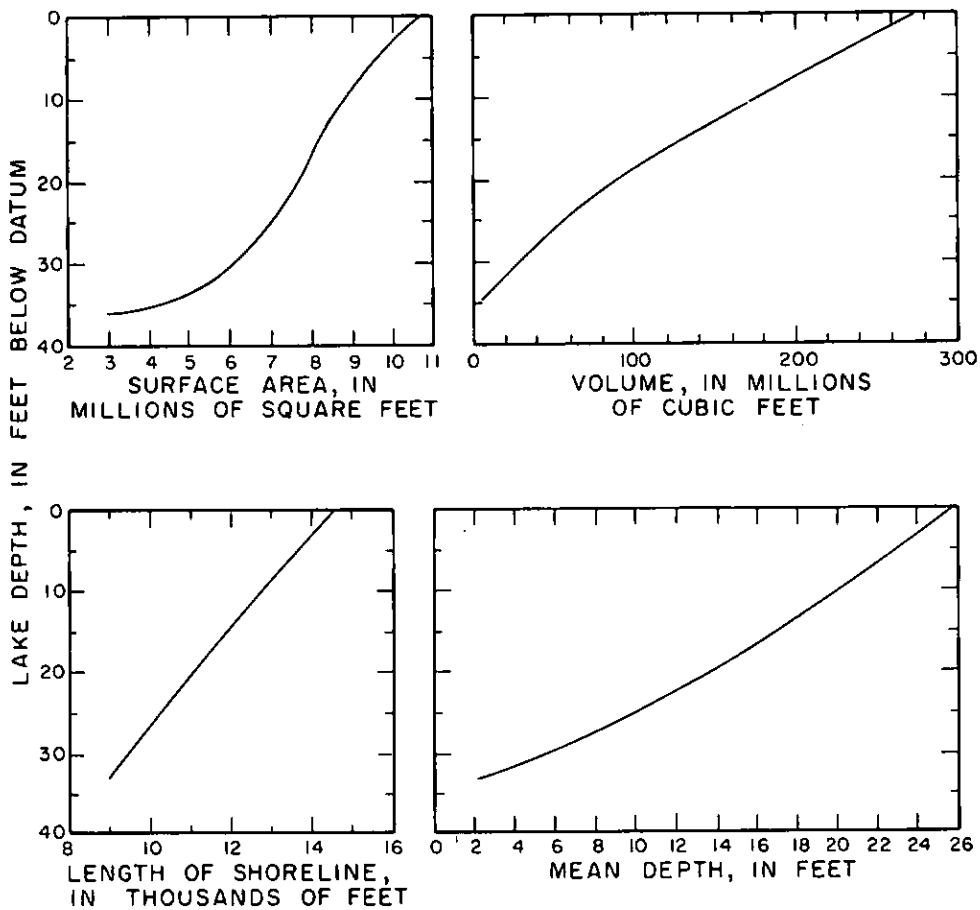


FIGURE 75. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Hancock Lake near Snoqualmie. Zero-depth datum is 2,167 feet above mean sea level, based on topographic-map altitude.

Figure 75 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 76 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

Lake stages.--Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-18-69	2,166.88
3-10-70	2,167.31
6-26-70	2,166.86
10-16-70	2,167.02
10-28-70	2,167.10

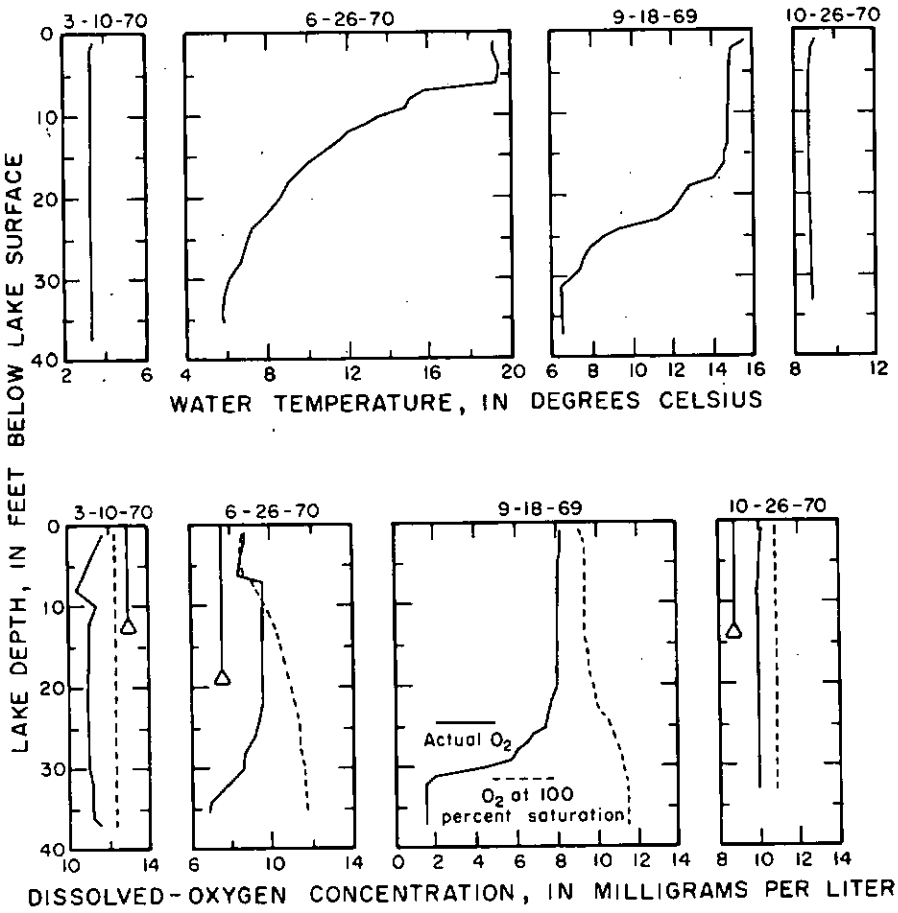


FIGURE 76. – Selected seasonal profiles of lake temperatures and DO concentration, Hancock Lake near Snoqualmie, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles.

Surface-water inflow and outflow.--Four inflow streams exist. The major inflow tributary, on the east end, contributes about 75 percent of the total inflow. Outflow from the lake is gaged by a U.S. Geological Survey stream-gaging station (12142300. Hancock Creek near Snoqualmie). Miscellaneous measurements of total surface-water inflow are:

Date	Inflow (in cfs)
9-18-69	41.8
3-10-70	17.9
6-26-70	14.1
10-16-70	13.0

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated	
Date of sampling	3-10-70	10-16-70
Depth of samples below surface, in ft	15	[a]3, 14, and 31
Silica (SiO_2)	3.9	3.9
Iron (Fe)	--	.00
Manganese (Mn)	--	.01
Calcium (Ca)	2.0	--
Magnesium (Mg)	.3	--
Sodium (Na)	.8	--
Potassium (K)	.1	--
Bicarbonate (HCO_3)	8	7
Carbonate (CO_3)	0	0
Sulfate (SO_4)	.0	1.2
Chloride (Cl)	1.1	.8
Fluoride (F)	.2	.1
Dissolved solids (residue at 180°C)	16	18
Hardness Ca-Mg	6	--
Hardness Noncarbonate	0	--
Alkalinity	7	6
pH, units	6.4	6.6
Color, Co-Pt units	10	10
Specific conductance, μmhos/cm	17	18

[a]Averages for three samples; constituents did not vary significantly.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-18-69	1	0.020	0.042	0.02	--	--	--	0.18
3-10-70	15	.013	.016	.08	--	--	--	.27
6-26-70	32	.003	.006	.08	--	--	--	1.80
10-16-70	3	.003	.006	.11	0.000	0.00	0.01	.11
10-16-70	14	.003	.003	.23	.000	.03	.04	.27
10-16-70	31	.003	.003	.11	.000	.00	.02	.12

Macrophytes.--Area of macrophytes 1.8 percent of lake area, October 16, 1970.

Horsetail (Equisetum), the dominant aquatic plant found, was concentrated in the southeast portion of the lake. Other plants found, in minor quantities, were waterlily (Nuphar) and buckbean (Menyanthes).

Remarks.--Below the lake a number of springs emerge from the hillside.

Conclusions.--Because of a high natural flushing rate, and in spite of the outdoor facilities and refuse-disposal practices of the seasonal residents on the lake's shore, Hancock Lake has a low biologic productivity, and probably is between the oligotrophic and mesotrophic stage of its life. The dissolved-oxygen profile in summer is orthograde in the metalimnion, and the hypolimnetic-oxygen deficit during stratification occurs in only a few feet of the near-bottom waters.

14222960. Merrill Lake near Cougar

Location.--Southernmost tip at lat 46°04'43", long 122°18'52"; lake in secs. 8, 9, 16, 17, and 21, T.7 N., R.4 E., Cowlitz County.

Origin.--Formed in a valley when a mudflow or flows blocked or dammed north end of valley.

The damming material originated northeast of the lake, and moved down the Kalama River valley.

Basin geology.--Predominantly bedded andesite breccia with interbedded andesite and basalt flows, mudflows and tuff beds.

Also included in the basin are tuffaceous and arkosic sandstones, shales and carbonaceous shale beds.

Soils.--Ashy, acid soils on mountainous uplands.

Land use and cover.--Mainly commercial forest land, has been and is being logged.

Tree types include fir, hemlock, and cedar, with a few alder, willow, balsam cottonwood, and maple groves near the shore of the lake. There is a State-operated camping area and boat ramp on the east side of the lake.

Population.--House count of October 1970 noted eight summer-use cabins on southwest corner of lakeshore; remainder of the basin unoccupied except for camping area.

Physical features of lake.--Littoral zone of lake composed of sand, silt, and muck forming a matrix for gravel to boulder-sized rocks.

Bathymetric map (fig.77) shown with the permission of R. W. Beck and Associates. Their survey was made August 25, 1969.

Some morphometric parameters, at a lake stage of 1,570 ft (msl), are:

Drainage area-------- 9.08 sq mi	Length of shoreline- 33,400 ft
Altitude of deepest part of lake (using msl datum)---------- 1,493 ft	Length of lake------ 12,050 ft
	Breadth of lake----- 3,270 ft
	Shoreline configuration-- 2.04
Surface area- 21.3 million sq ft	Development of volume---- 0.50
Lake volume--- 817 million cu ft	Relative depth--- 1.48 percent
Mean depth---------- 38.4 ft	Mean slope---------- 4°38'
Maximum depth---------- 77 ft	

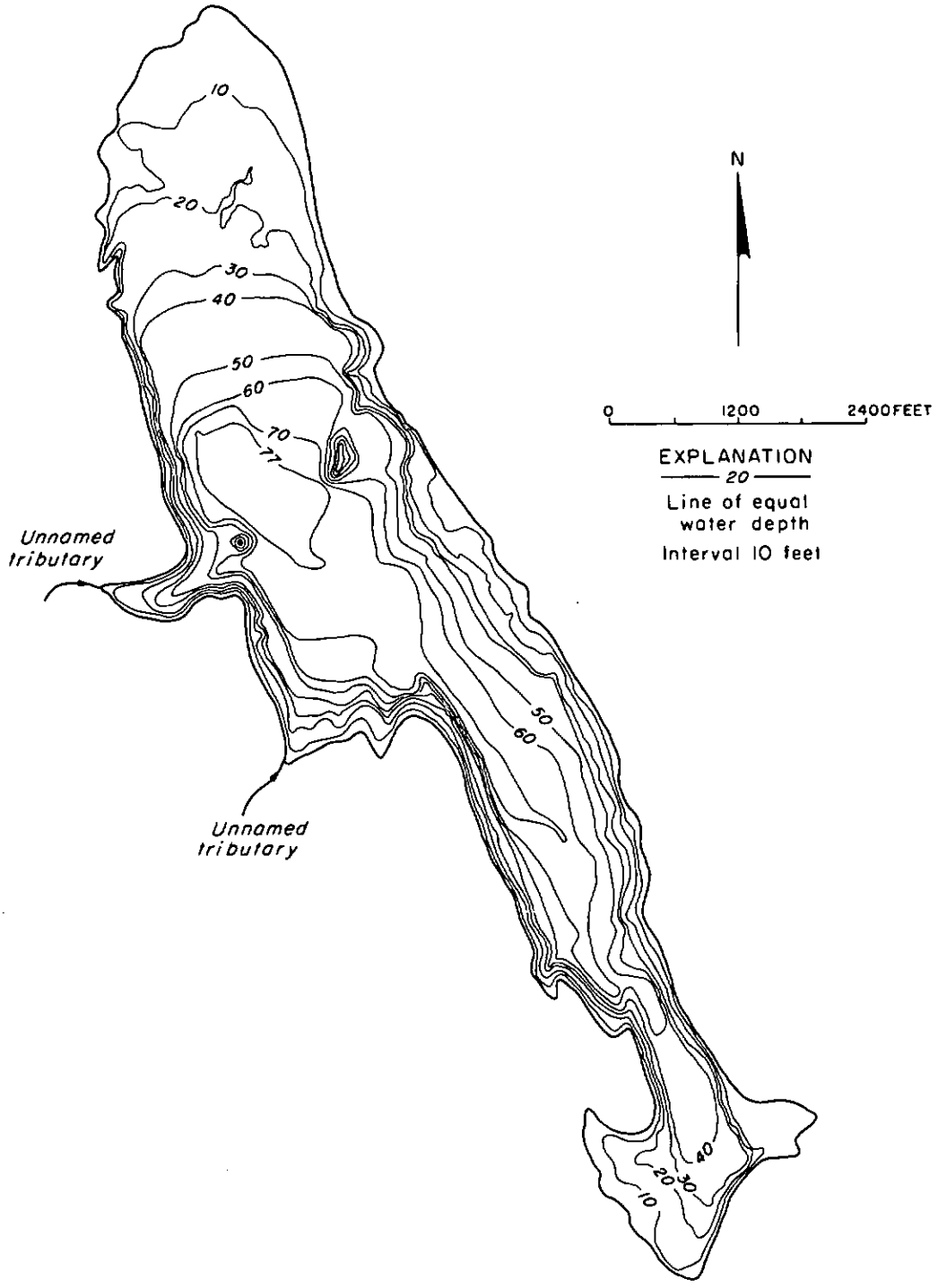


FIGURE 77. – Merrill Lake near Cougar, with contours showing lake bottom. Datum is mean sea level. Based on 27 cross-sectional depth profiles. Adapted from unpublished map by R.W. Beck and Associates. Zero-depth contour is 1,570 feet above mean sea level.

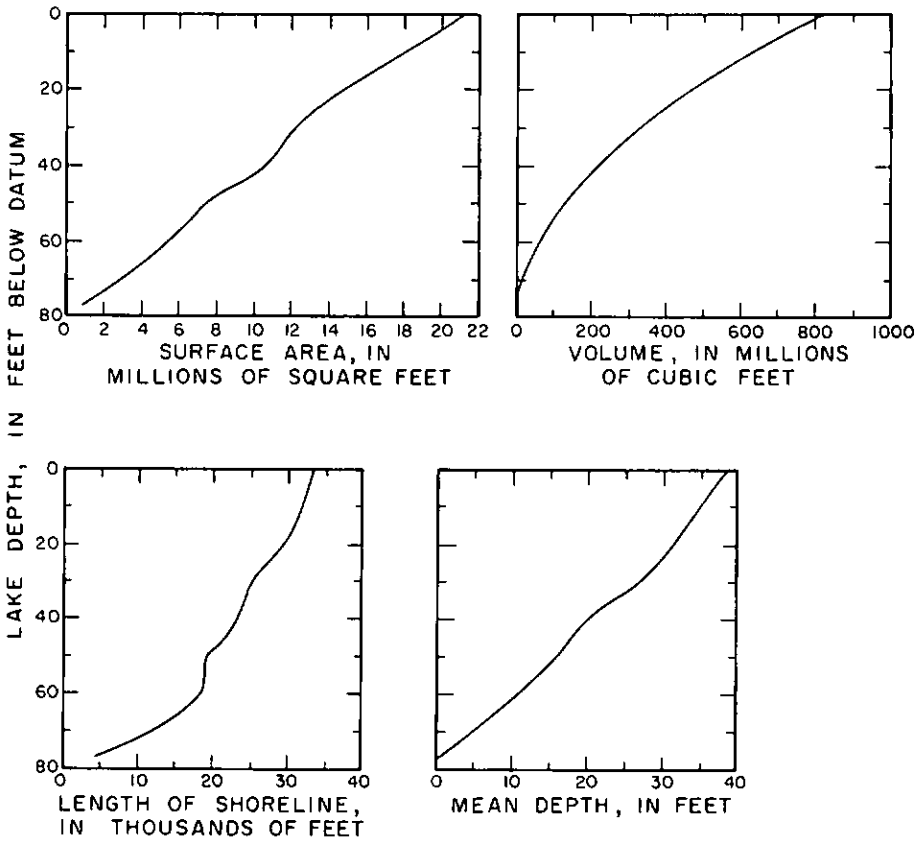


FIGURE 78. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Merrill Lake near Cougar. Zero-depth datum is 1,570 feet above mean sea level.

Figure 78 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 79 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

Suspended sediment and turbidity are shown in the following list of sediment concentration and turbidity taken on July 22, 1970, at several depths:

Depth of sample from lake surface (ft)	Suspended sediment concentration (mg/l)	Turbidity, Jackson candle units
3	4	0
18	4	0
20	4	0

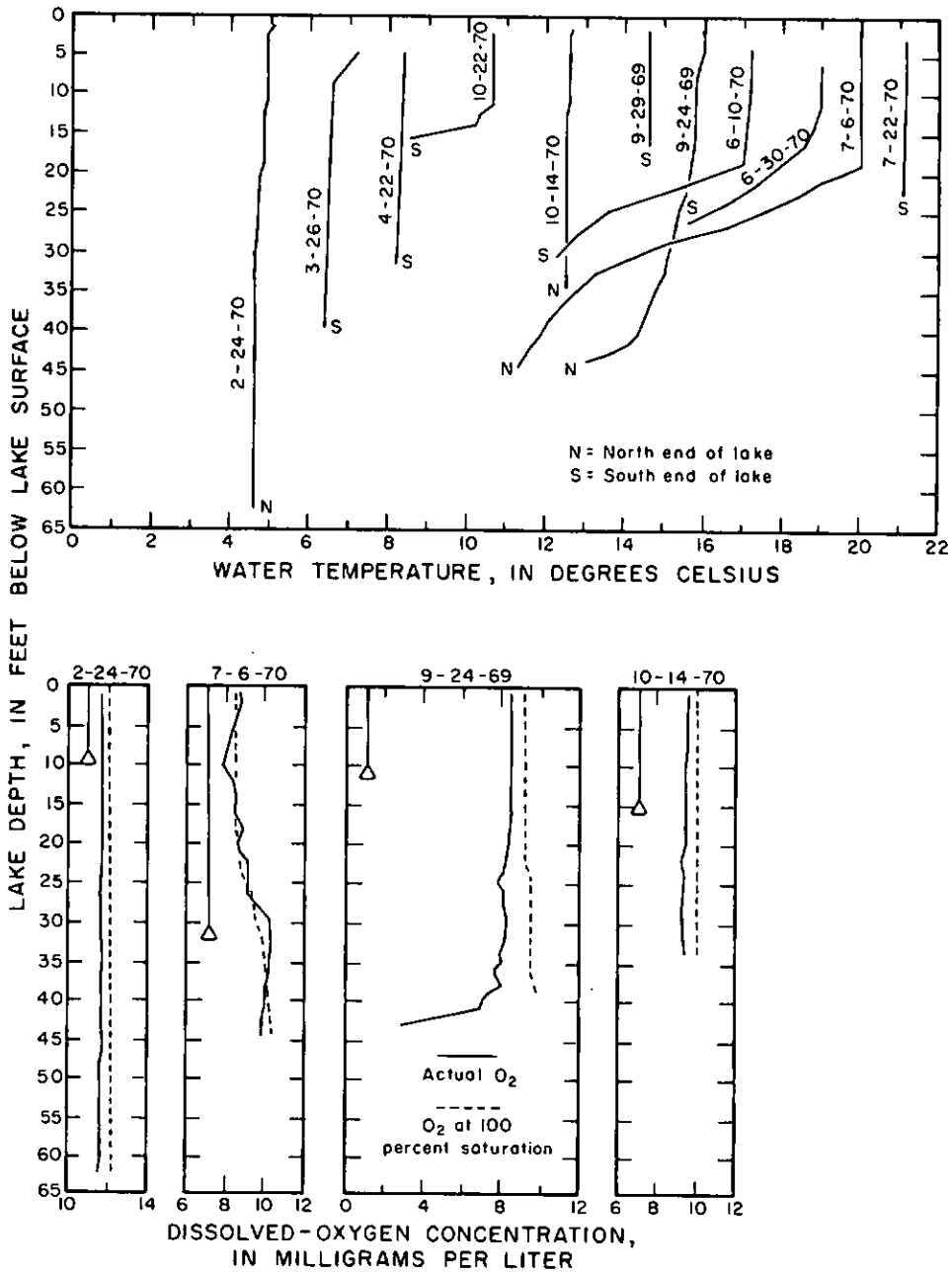


FIGURE 79. – Selected seasonal profiles of lake temperature and DO concentration, Merrill Lake near Cougar, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profile.

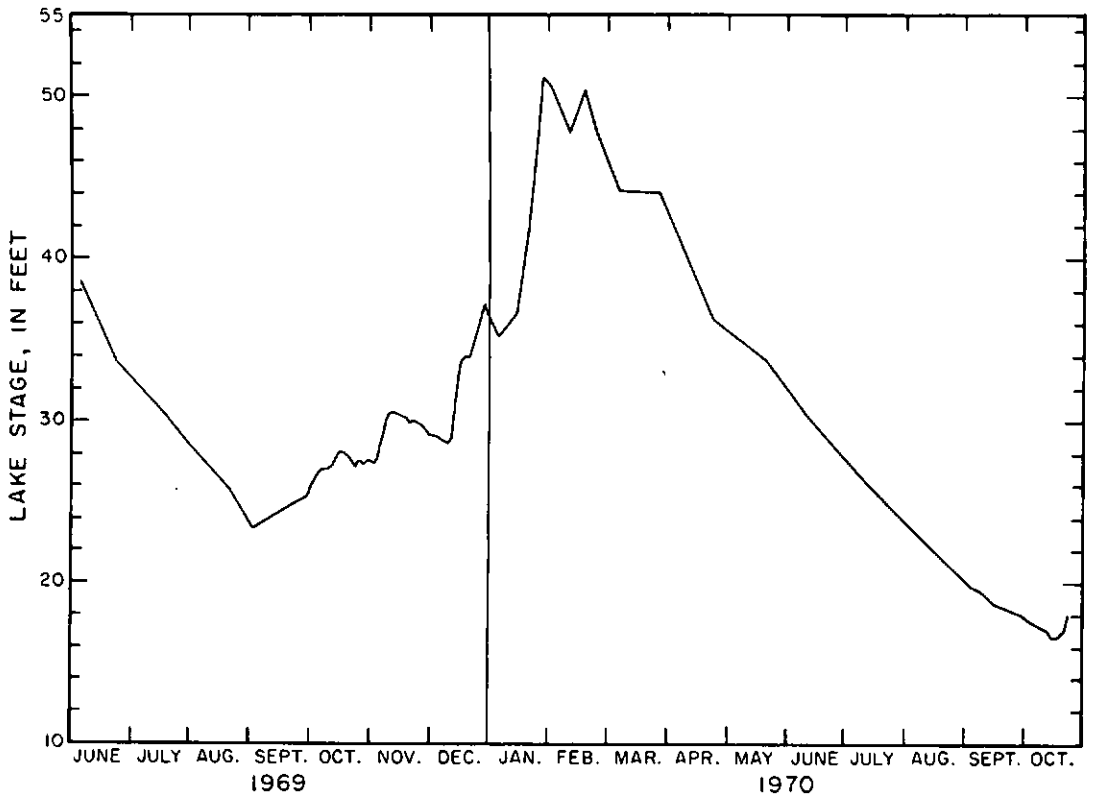


FIGURE 80. – Observed lake stages, Merrill Lake near Cougar. Datum is 1,512 feet above mean sea level.

Lake stages.--Figure 80, hydrograph for June 1969-October 1970 period of observation.

Fluctuations in lake stage are as much as 35 ft annually.

Miscellaneous measurements of lake stages obtained during the sampling periods for this study are:

Date	Lake stage (in ft above msl)
9-24-69	1,537.17
2-24-70	1,560.44
7- 6-70	1,539.08
10-14-70	1,528.95

Surface-water inflow and outflow.--No visible surface outflow.

There are three surface-water inflow streams, all flowing into the northwest part of the lake. During this

study the following total amounts of surface-water inflow were measured:

Date	Inflow (in cfs)
2-24-70	15.4
7- 6-70	2.0
10-14-70	1.48

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated			
Date of sampling	1-19-70	2-24-70	5-19-70	10-14-70
Depth of samples below surface, in ft	18	25	18	[a] 3,17,and 32
Silica (SiO_2)	7.2	7.3	7.1	4.7
Iron (Fe)	--	--	--	.00
Manganese (Mn)	--	--	--	.00
Calcium (Ca)	3.1	2.0	2.1	--
Magnesium (Mg)	.5	.4	.4	--
Sodium (Na)	1.4	1.1	1.5	--
Potassium (K)	.2	.1	.2	--
Bicarbonate (HCO_3)	12	11	13	14
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	.4	.6	.0	.2
Chloride (Cl)	2.3	.5	.4	.7
Fluoride (F)	.0	.1	.1	.0
Dissolved solids (residue at 180°C)	26	19	19	19
Hardness Ca-Mg	10	7	7	--
Hardness Noncarbonate	0	0	0	--
Alkalinity	10	9	11	11
pH, units	6.9	6.8	7.0	7.0
Color, Co-Pt units	0	0	0	0
Specific conductance, μmhos/cm	32	20	23	24

[a] Averages for three samples; constituents did not vary significantly.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter: Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-24-69	1	0.000	0.006	0.00	--	--	--	0.02
1-19-70	18	--	--	.00	--	--	--	--
2-24-70	25	.000	.010	.02	--	--	--	.02
5-19-70	18	--	--	.02	--	--	--	--
7- 6-70	44	.003	.010	.02	--	--	--	1.80
10-14-70	3	.003	.003	.04	0.000	0.00	0.00	.00
10-14-70	17	.003	.006	.17	.000	.00	.00	.07
10-14-70	32	.006	.006	.10	.000	.00	.01	.10

Macrophytes.--Aquatic-plant survey on October 14, 1970.

Lake seemed void of any hydrophytes, although some riparian vegetation, mainly willows (Salix and Spiraea), were found along the edge of the high-water stage.

Remarks.--The lake is undergoing a feasibility study for a pumped storage project to produce hydroelectic power.

Northeast of the lake large springs flow from the hillside into the Kalama River drainage system.

Conclusions.--The exceptionally large range in lake-level fluctuations of Merrill Lake may account for the lack of shoreline macrophyte production and is an indication of the high flushing character of the lake. This oligotrophic lake has a very low biologic productivity, as shown by a near orthograde dissolved-oxygen profile in summer, the deep transparency of the water, the low specific conductance, and the low winter-nutrient content.

14225400. Packwood Lake near Packwood

Location.--Surface-water outlet at lat 46°35'47", long 121°34'07"; lake in secs. 28, 33, and 34, T.13 N., R.10 E., Lewis County.

Origin.--Occupies part of a glaciated valley.

A landslide or slides, probably from the north, dammed the valley. The island in the lake is a remnant of a slide.

Basin geology.--Predominantly bedded andesite and basalt flows, mudflows, and tuff beds.

Also found in the basin are tuffaceous and arkosic sandstones, shales, and carbonaceous shales.

Soils.--Ashy, acid soils on mountainous uplands.

Land use and cover.--Forest and recreational area, classified as wilderness lake.

The lake also is used for hydroelectric-power generation. Predominantly evergreen trees, such as fir, cedar and hemlock form the forest cover. Some alder, willow, and maple are found southwest of the lake in upper Lake Creek valley.

Population.--Concentrated at north end, a five-building resort, a forest-service cabin, and a hydroelectric plant intake and diversion structure.

Along the north and east sides of the lake there are forest-service maintained campgrounds.

Physical features of lake.--Littoral zone of lake composed of bedrock, highly faceted gravels and boulders and, in places, rocks from talus slopes. Where the tributary inflows form deltas (south end of the lake) and near the outlet, sand, silt, and muck are found.

Bathymetric map shown in figure 81.

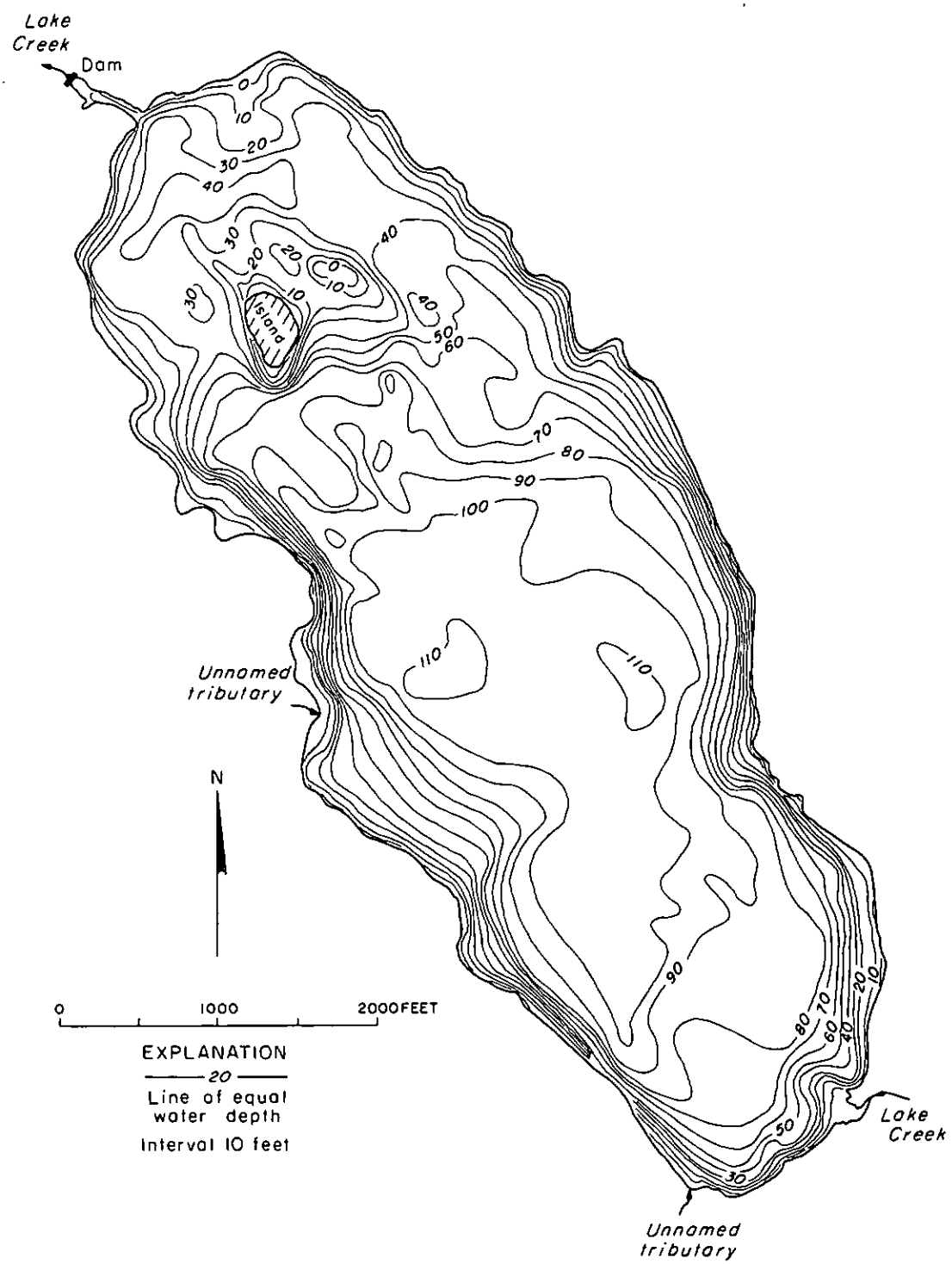


FIGURE 81. – Packwood Lake near Packwood, with lake bottom shown by 10-foot contours, based on mean sea level datum and 20 cross-sectional depth profiles mapped by U.S. Geological Survey, July 1970. Lake stage is 2,856.4 feet above mean sea level.

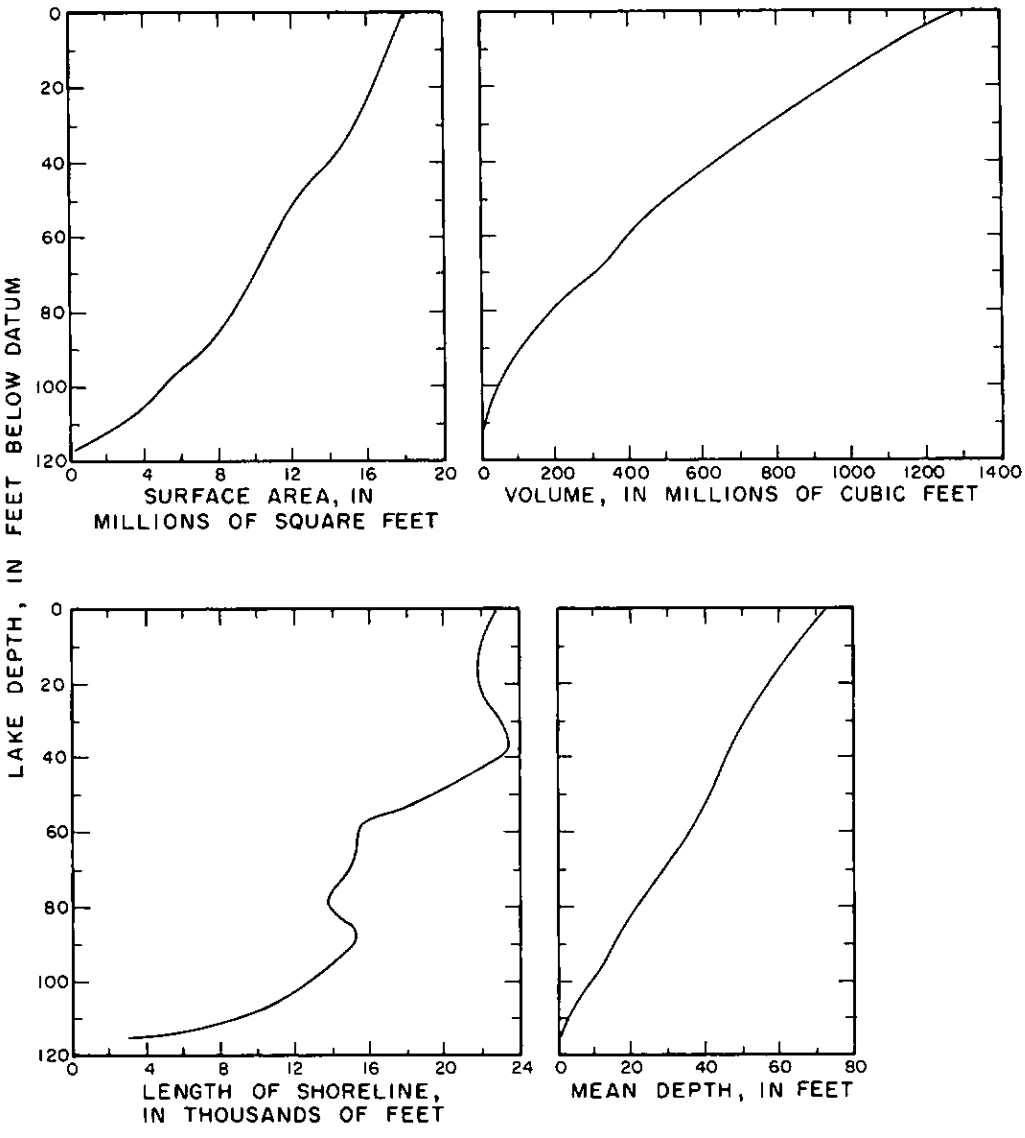


FIGURE 82. – Relations of surface area, volume, length of shoreline, and mean depth to lake depth, Packwood Lake near Packwood. Zero-depth datum is 2,856.4 feet above mean sea level.

Some morphometric parameters, at a lake stage of 2,856.4 ft (msl), are:

Drainage area	19.2 sq mi
Altitude of deepest part of lake (using msl datum)	2,740 ft
Surface area	17.4 million sq ft
Lake volume	1,240 million cu ft
Mean depth	70.8 ft
Maximum depth	117 ft
Length of shoreline	22,500 ft
Length of lake	7,800 ft
Breadth of lake	3,100 ft
Shoreline configuration	1.50
Development of volume	0.61
Relative depth	2.46 percent
Mean slope	6°30'

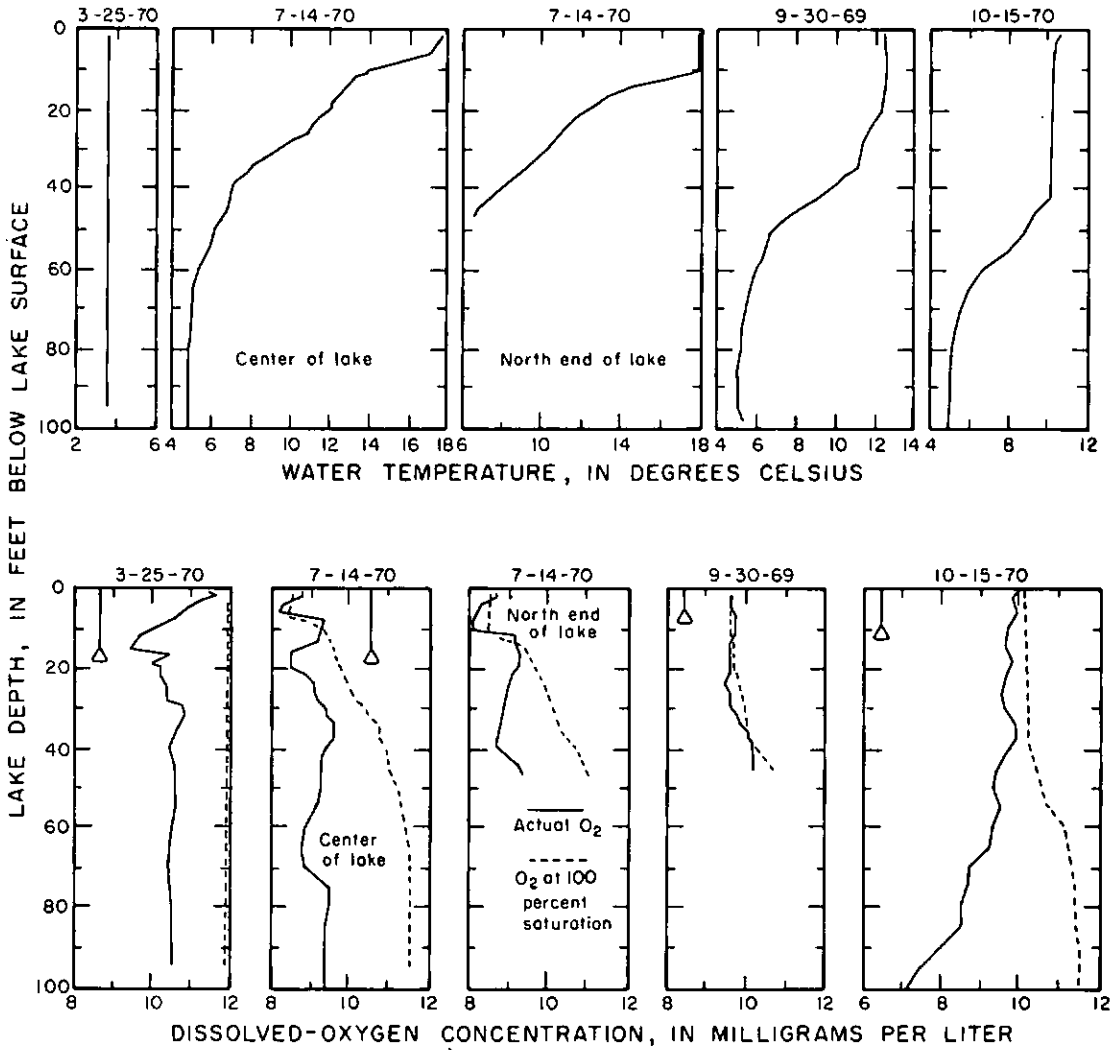


FIGURE 83. – Selected seasonal profiles of lake temperature and DO concentration, Packwood Lake near Packwood, 1969-70. Secchi-disc transparency depths are shown by base of triangles on DO profiles. All profiles taken in deepest part of lake unless noted otherwise.

Figure 82 shows relations of area, volume, length of shoreline, and mean depth to stage; figure 83 shows profiles of DO concentration, water temperature, and Secchi-disc transparency depths.

Lake stages.--Hydrograph of monthly maximum and minimum lake stages shown in figure 84.

Lake is controlled by a low concrete dam at outlet, completed during October 1963. Draft from the lake, for continuous power generation, began June 1, 1964. Lake-stage regulation is allowed between 2,850.5 and 2,858.5 ft.

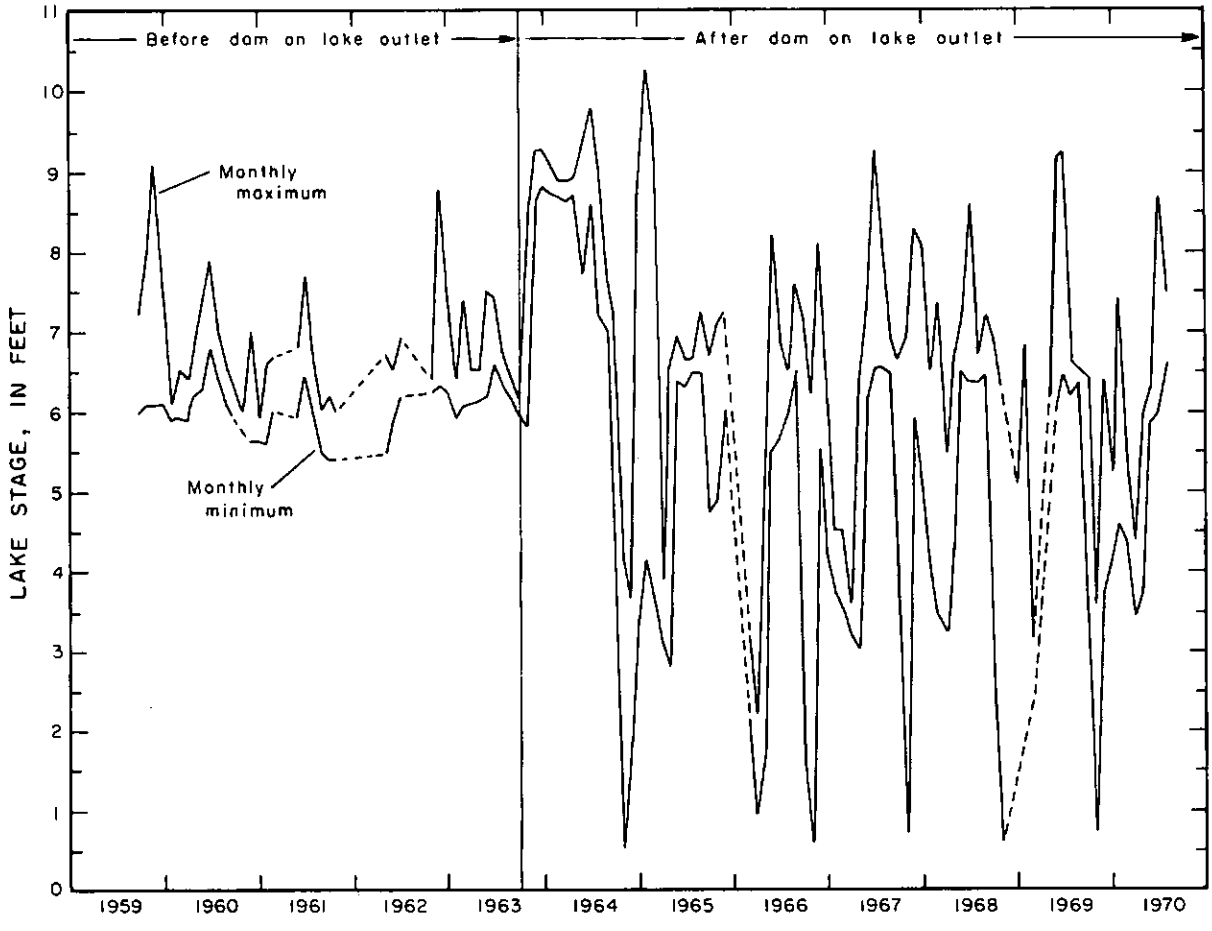


FIGURE 84. – Monthly maximum and monthly minimum lake stages, Packwood Lake near Packwood, 1959-70. Dashed lines indicate estimated periods. Zero-depth datum is 2,856.4 feet above mean sea level.

However, during the summer season the elevation of the lake is maintained between 2,856.5 and 2,857.5 ft for forestry and fisheries protection and esthetic value. Miscellaneous measurements of lake stages are:

Date	Lake stage (in ft above msl)
9-29-69	2,852.99
9-30-69	2,852.97
3-25-70	2,853.45
7-14-70	2,856.70
10-15-70	2,852.70

Surface-water inflow and outflow.--Surface-water inflow, from eight tributaries to lake, four are intermittent, flowing only during winter or periods of heavy precipitation.

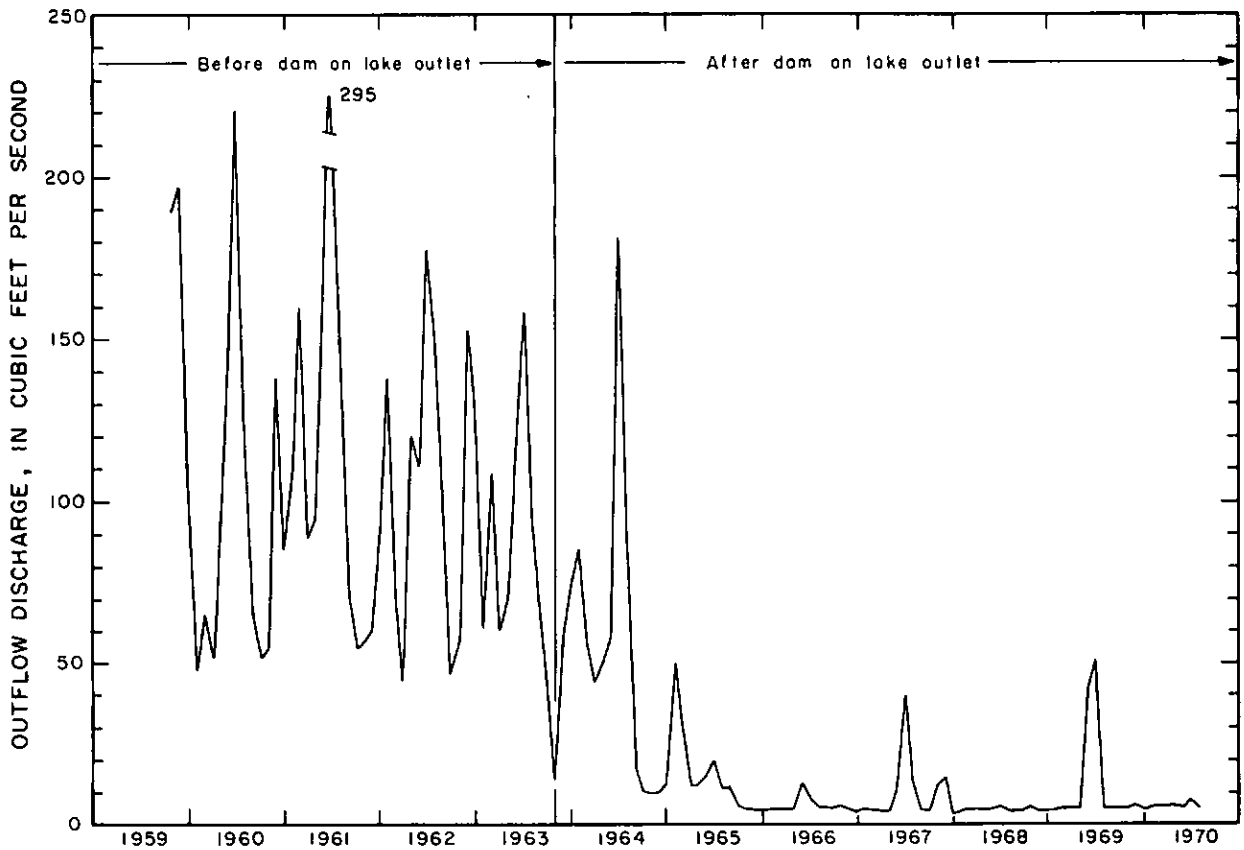


FIGURE 85. – Monthly mean discharge from outlet of Packwood Lake (14225500. Lake Creek near Packwood), 1959-70. Water diverted for hydroelectric power generation is not included in the discharge.

Outflow is through Lake Creek. Since June 1, 1964, flow to Lake Creek has been regulated by continuous operation of the powerplant which controls and diverts the outflow of the lake. Water diverted for hydroelectric power generation is not returned to Lake Creek. Flow to Lake Creek, only, is gaged by the U.S. Geological Survey (14225500. Lake Creek near Packwood). A hydrograph of Lake Creek outflow, not including diversions, is shown in figure 85.

Total inflow and outflow of the lake during times of lake sampling are shown in the following list.

Date	Inflow (in cfs)	Outflow (in cfs)
9-29-69	40.9	114
3-25-70	42.3	51
7-14-70	90.0	99
10-15-70	28.2	5

Chemistry of lake waters:

General chemical characteristics:

Item	Values in milligrams per liter unless otherwise indicated		
Date of sampling	3-25-70	10-15-70	10-15-70
Depth of samples below surface, in ft	1	[a]3 and 50	100
Silica (SiO_2)	12	12	13
Iron (Fe)	--	.00	.00
Manganese (Mn)	--	.02	.02
Calcium (Ca)	7.6	--	--
Magnesium (Mg)	.9	--	--
Sodium (Na)	2.3	--	--
Potassium (K)	.4	--	--
Bicarbonate (HCO_3)	28	28	31
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	2.4	1	1.2
Chloride (Cl)	.8	.3	.4
Fluoride (F)	.1	.1	.1
Dissolved solids (residue at 180°C)	43	44	45
Hardness Ca-Mg	23	--	--
Hardness Noncarbonate	0	--	--
Alkalinity	23	23	25
pH, units	7.1	7.2	6.9
Color, Co-Pt units	5	0	0

[a]Averages for two samples; constituents did not vary significantly.

Graphs of specific conductance versus depth are shown in figure 86.

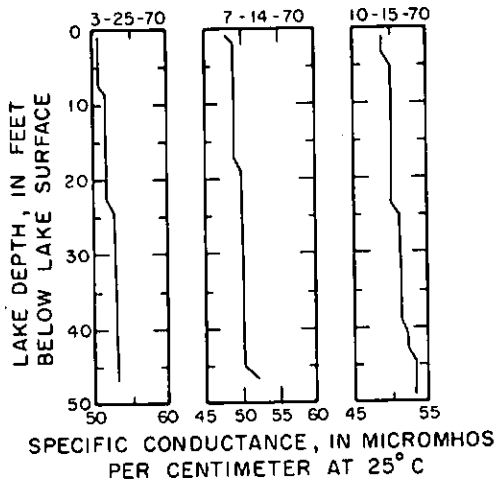


FIGURE 86. – Selected seasonal profiles of specific conductance, Packwood Lake near Packwood, 1969-70.

Major nutrients:

Date	Depth sampled (ft below surface)	Milligrams per liter						
		Orthophosphate (PO_4) as phosphorus (P)	Total phosphate (PO_4) as phosphorus (P)	Nitrate (NO_3) as nitrogen (N)	Nitrite (NO_2) as nitrogen (N)	Ammonia (NH_3) as nitrogen (N)	Total organic nitrogen (N)	Total nitrogen (N)
9-30-69	1	0.003	0.006	0.00	--	--	--	0.04
3-25-70	1	.003	.026	.02	--	--	--	.02
7-14-70	103	.003	.006	.04	--	--	--	.16
10-15-70	3	.006	.010	.02	0.000	0.00	0.01	.20
10-15-70	50	.003	.003	.09	.000	.00	.00	.09
10-15-70	100	.006	.006	.04	.000	.00	.01	.05

Macrophytes.--Area of macrophytes 0.4 percent of lake area, October 15, 1970.

Horsetail (Equisetum) accounted for 0.2 percent of the aquatics and was found to occupy areas along the high-water line near inflow tributaries. Other water plants, found near the main flow (upper Lake Creek) and near the resort, included waterweed (Elodea) and pondweed (Potamogeton).

Conclusions.--Packwood Lake has very low biologic productivity. The water of the lake is glacial in origin, resulting in the shallower transparency values as compared to those of other high-altitude lakes studied. The summer dissolved-oxygen content in the lake is characterized by a poorly developed clinograde profile which becomes orthograde--an oligotrophic condition--in the metalimnion zone. The macrophytes at the undeveloped end of the lake--near the major inflow--were found to be a type commonly occurring naturally in the other high-altitude lakes. The macrophytes at the developed end of the lake near the resort are similar to those found in the lowland lakes and are indicative of some enrichment.


U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849